

Attachment C
SWIFTRC UIC Inventory
Information Package

SWIFT Research Center Aquifer Monitoring and Contingency Plans for Managed Aquifer Recharge

Prepared for

United States Environmental Protection Agency

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Executive Summary

The Hampton Roads Sanitation District (HRSD) Sustainable Water Initiative for Tomorrow (SWIFT) will add multiple advanced water treatment processes to select HRSD wastewater treatment facilities to produce a highly treated water (SWIFT Water) that exceeds drinking water standards and is compatible with the receiving aquifer. Secondary effluent from up to seven of HRSD's existing treatment facilities will be treated at SWIFT facilities and SWIFT Water will be recharged into the Potomac Aquifer System (PAS) to counter depleting aquifer levels. At full-scale, HRSD intends to recharge over 100 million gallons per day (mgd) of SWIFT Water that will significantly reduce the nutrient load to the sensitive Chesapeake Bay and provide significant benefit to the region by limiting saltwater intrusion, reducing land subsidence, and providing a sustainable source of groundwater, a necessity for continued economic expansion in the region.

The SWIFT Research Center (SWIFTRC) involves a nominal 1 mgd advanced treatment facility and injection well located at the Nansemond Treatment Plant (Suffolk, VA) (Figure 1-1) that will begin production and recharge in spring 2018. The primary purpose of the SWIFTRC is to demonstrate at a meaningful scale that the SWIFT Water meets primary drinking water standards and is compatible with the groundwater chemistry and minerals composing the PAS. HRSD will collect at least 18 months of operational data to inform and optimize the design and construction and to define permitting requirements for the full-scale SWIFT facilities.

This document is an attachment within the Underground Injection Control (UIC) Inventory Information Package ("UIC Inventory"). The purpose of this document, Attachment C, is to describe the monitoring and contingency plans for evaluating the hydraulic and water quality response of the PAS and to establish a guideline for conducting a field scale soil aquifer treatment (SAT) study. The key topics presented in this document are listed here:

1. SWIFT Water from the SWIFTRC will be injected into the upper, middle, and lower zones of the Potomac Aquifer System (PAS) through a test injection well (TW-1). Water quality after injection will be monitored through a variety of monitoring wells:
 - a. MW-SAT: a multi-aquifer monitoring well (MW-SAT) located 50 feet away from TW-1;
 - b. MW-UPA, MW-MPA, and MW-LPA: conventional monitoring wells screening the upper, middle, and lower zones of the aquifer located 400-500 feet south of TW-1.
2. TW-1 will be conditioned by injecting and then recovering aluminum chloride and sodium hydroxide before operations begin to mitigate swelling and dispersion of clay materials in the PAS.
 - a. The conditioning protocol, including the recovery of conditioning fluids, will be tested at MW-LPA prior to TW-1.
3. Monitoring of the wells will be accomplished by pumping samples from various aquifer depths directly to the SWIFTRC lab for sample collection and subsequent analysis.
4. The SWIFT Water will be analyzed for a host of analytes on a regular basis to evaluate its compatibility with the PAS. Well clogging potential will be evaluated through regular measurement of the Bypass Filtering Index (BFI) and the Micro-Fouling Index (MFI). Real-time well clogging will be monitored by injection pressure logging and downhole flow control valve operation.
5. Backflushing of TW-1 will be conducted on a regular basis to maintain well injectivity.
6. At an injection rate of 1 mgd, the travel time from TW-1 to MW-SAT is estimated to be between less than 1-day and 6-days; travel time to MW-UPA, MW-MPA, and MW-LPA will likely range between

100-days and 1-year. Travel time is highly dependent on how the recharge water disperses across the aquifer.

7. Measurement of chloride and conductivity will be used as a tracer to evaluate the movement of water to MW-SAT and beyond and the mixing between recharge and native groundwater.
8. Once recharge water is detected at MW-SAT, a comprehensive suite of analytes will be monitored at 12-hour intervals for a period of one week, followed by less frequent monitoring depending on the initial sampling and analysis results. Once recharge water is detected at the distant monitoring wells (MW-UPA, MW-MPA, and MW-LPA), a comprehensive suite of analytes will change from being monitored on a weekly basis to a daily basis until water quality approximates SWIFT Water.
9. Monitoring well MW-SAT will provide early data on aquifer response, and will serve multiple roles including:
 - a. Characterizing hydrodynamic factors (advection, dispersion, diffusion, mixing, etc.) influencing solute transport in the PAS.
 - b. Quantifying the attenuation and removal/treatment of major constituents in the recharge, including dissolved oxygen, nitrate, Total Kjeldahl nitrogen (TKN), phosphorus, orthophosphate, total organic carbon (TOC), dissolved organic carbon, chemical oxygen demand (COD), contaminants of emerging concern, and several others.
 - c. Monitoring the leaching of undesirable metals from minerals in the PAS including iron, manganese, and arsenic.
 - d. Describing redox conditions at the interface between recharge and native groundwater as well as helping determine the magnitude of cation exchange between the recharge and aquifer.
10. Contingency plans are included that identify actions to be taken for loss of well injectivity and exceedances of MCLs in water sampled at monitoring wells.

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Acronyms and Abbreviations

µg/L	micrograms per liter
AlCl ₃	aluminum chloride
ASR	aquifer storage and recovery
BFI	Bypass Filtering Index
CEC	contaminants of emerging concern
CFE	combined filter effluent
COD	chemical oxygen demand
DO	dissolved oxygen
DOC	dissolved organic carbon
EPA	U.S. Environmental Protection Agency
fbg	feet below grade
GAC	Granular Activated Carbon
gpm	gallons per minute
HAA	haloacetic acids
HRSD	Hampton Roads Sanitation District
LPA	Lower zone of the aquifer
MAR	Managed Aquifer Recharge
MFI	Micro-Fouling Index
MG	million gallons
mgd	million gallons per day
mg/L	milligrams per liter
mm	millimeters
NDMA	<i>N</i> -Nitrosodimethylamine
NTU	nephelometric turbidity units
ORP	Oxidation-Reduction Potential
PAS	Potomac Aquifer System
pCi/L	picocuries per liter
PMCL	Primary Maximum Contaminant Levels
PRV	pressure-reducing valve
PVFD	polyvinylidene fluoride
SAT	soil aquifer treatment
SDWA	Safe Drinking Water Act
SWIFT	Sustainable Water Initiative for Tomorrow

ACRONYMS AND ABBREVIATIONS, CONTINUED

SWIFTRC	SWIFT Research Center
SWPI	SWIFT Water performance indicators
TDS	total dissolved solids
TKN	Total Kjeldahl nitrogen
TOC	total organic carbon
TSS	total suspended solids
UIC	Underground Injection Control
WWTP	Wastewater Treatment Plant

SWIFT Research Center Well Facilities

The facilities associated with Managed Aquifer Recharge (MAR) activities at the SWIFT Research Center (SWIFTRC) include the test injection well (TW-1), a multi-aquifer monitoring well (MW-SAT) located 50 feet away from TW-1, conventional monitoring wells screening the upper, middle, and lower zones of the Potomac Aquifer (MW-UPA, MW-MPA, MW-LPA) located approximately 400 - 500 feet south of TW-1, (Figure 1-2). Finished water will leave the SWIFTRC and be pumped to TW-1. To discriminate between monitoring the SWIFT advanced water treatment processes and monitoring the aquifer response to MAR, this plan describes water exiting the advanced water treatment facility as “SWIFT Water”, and describes water being injected into TW-1 as “recharge water”.

The Hampton Roads Sanitation District (HRSD) will have the capability to measure field chemistry and collect samples of the SWIFT Water, native groundwater from the monitoring wells, and recharge water from the monitoring wells at stations within the SWIFTRC. The approach will require installing pumps in the monitoring wells and connecting the wells with the SWIFTRC.

The sampling stations will be equipped with instrumentation appropriate for monitoring the quality of these water types, work areas for sample preparation, and drains that allow disposal of the water. Moreover, water level monitoring instrumentation installed in the monitoring wells will record the hydraulic water level and display the levels at the SWIFTRC control room.

1.1 Managed Aquifer Recharge Well

1.1.1 Recharge Well Construction

The SWIFT Managed Aquifer Recharge Well (TW-1) extends to 1,410 feet below grade (fbg) and features a 12-inch diameter carbon steel casing and 380 feet of stainless steel, 0.04-inch slot, continuous wire wrap screen (Figure 1-3). TW-1 screens the Upper (120 feet), Middle (125 feet), and upper portion of the Lower (135 feet) zones of the Potomac Aquifer System (PAS). The static water level in TW-1 reflects combined heads from each aquifer and fluctuates around 95 fbg. Water levels measured from the isolated aquifer units during packer testing varied from 95 to 97 fbg.

TW-1 will be equipped with a pressure transducer to measure and record static, injection, and backflushing water levels during MAR operations. Groundwater samples will be collected from TW-1 before starting MAR operations, to establish background conditions of the native groundwater. HRSD will monitor the quality of the SWIFT Water inside the SWIFTRC, as discussed in Attachment B of SWIFTRC Underground Injection Control (UIC) Inventory. To accommodate potential sampling at TW-1 during recharge or backflushing operations, the wellhead piping will contain a manually operated sample tap.

1.1.2 Pre-Recharge Aquifer Conditioning around TW-1

Formation damage is well documented during MAR operations in the PAS of southeastern Virginia (Brown and Silvey). The U.S. Geological Survey conducted test cycles at a pilot aquifer storage and recovery (ASR) facility in Norfolk, Virginia, during the early 1970s. Recharge exhibiting an ionic strength of 0.0001 moles per liter (M) was injected into a test well screening the UPA and MPA, where the ionic strength of the native groundwater equaled 0.01 M. The specific capacity (injectivity) of the test well declined by nearly 80 percent in the first 90 minutes after commencing recharge, reducing the capacity of the ASR well by a similar amount, and effectively ending the practical aspects of the project. The project continued for several years, but injectivity and injection capacity losses proved irreversible.

Recharge entering TW-1 will exhibit an ionic strength averaging slightly less than one order of magnitude less than groundwater in the PAS. Exposing clay minerals to waters of lower ionic strength characteristic of the recharge water reduces the ambient charge in the pore water around the minerals. The reduction in charge causes the minerals to expand, disperse, and separate from connections to other clay particles and aquifer framework minerals. The loosened fragments migrate and lodge in pore spaces, leading to a reduction of the capacity of the injection well.

To prevent the swelling and dispersion of clay minerals in the PAS during recharge, the clay minerals (sodium montmorillonite, kaolinite, illite, and chlorite) around the wellbore of TW-1 will be conditioned to a distance of 20 feet with an aluminum chloride solution (Appendix 1). The solution will consist of 0.1 M aluminum chloride and mixed in potable water (Reed, 1972). To ensure the solution disperses relatively evenly across the PAS in TW-1, HRSD will isolate individual or several intervals screening the upper, middle and lower PAS zones using packers when applying the conditioning solution. Potable water will then be flushed down the well, and the solution will remain in the PAS for two weeks. At the end of two weeks, the spent conditioning solution from TW-1 will be recovered and disposed of by directing the flow to the headworks of the Nansemond Treatment Plant.

To evaluate the effectiveness of the conditioning procedure, an aluminum chloride treatment was piloted in MW-LPA, a monitoring well screening the Lower Potomac Aquifer. The pilot treatment event (starting 10/24/17) employed a 0.1 molar AlCl_3 solution and conditioned an aquifer volume extending an estimated 20 feet from the well. In a post-treatment step drawdown test, the pumping specific capacity at MW-LPA improved by 20 percent. More important, the hydraulic characteristics of MW-LPA remained stable during a 7-day injection test conducted after the treatment.

Should the treatment had proven a failure, the injection capacity of MW-LPA would have declined precipitously within several hours of starting the test similar to the testing conducted by the U.S. Geological Survey. The volume of potable water used during the post treatment recharge test far exceeded the volume of AlCl_3 injected (extending beyond the 20-foot treated radius). Thus, potable water migrated outside the treated zone around MW-LPA without showing signs of clay degradation and clogging. The testing also confirmed the viability of a 20-foot treatment zone.

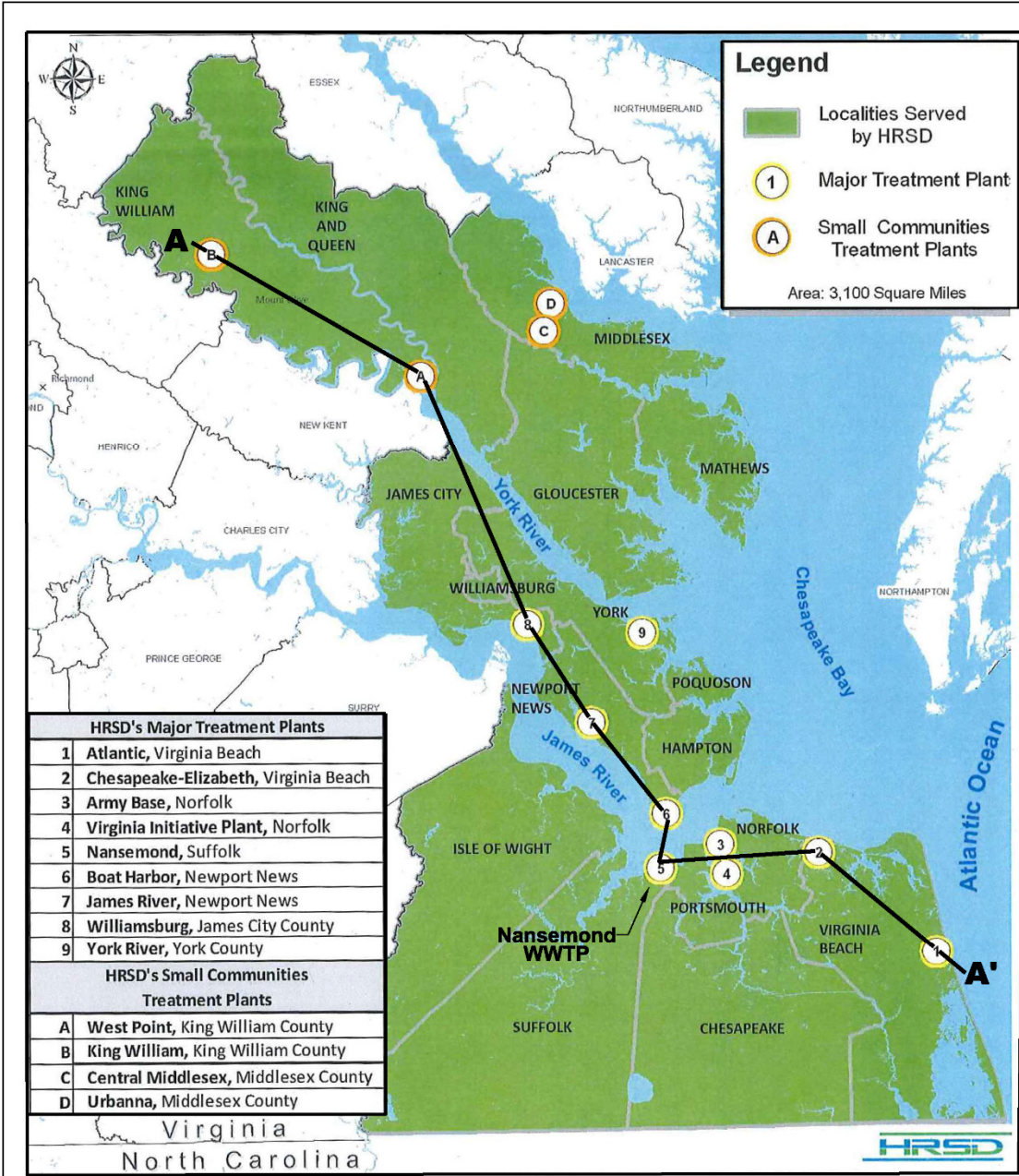


Figure 1-1
Location Map of Hampton Roads Sanitation District and Section Line A - A'
Hampton Roads Sanitation District
Virginia Beach, VA

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Legend

- * MW-SAT with Depth-Discrete Sampling System
- Test Well TW-1, Conventional Monitoring Wells, MW-UPA, MPA & LPA

Figure 1-2
**Location Map of TW-1, MW-SAT,
 MW-UPA, MW-MPA, and MW-LPA
 at Nansemond WWTP**
 Hampton Roads Sanitation District
 Virginia Beach, VA

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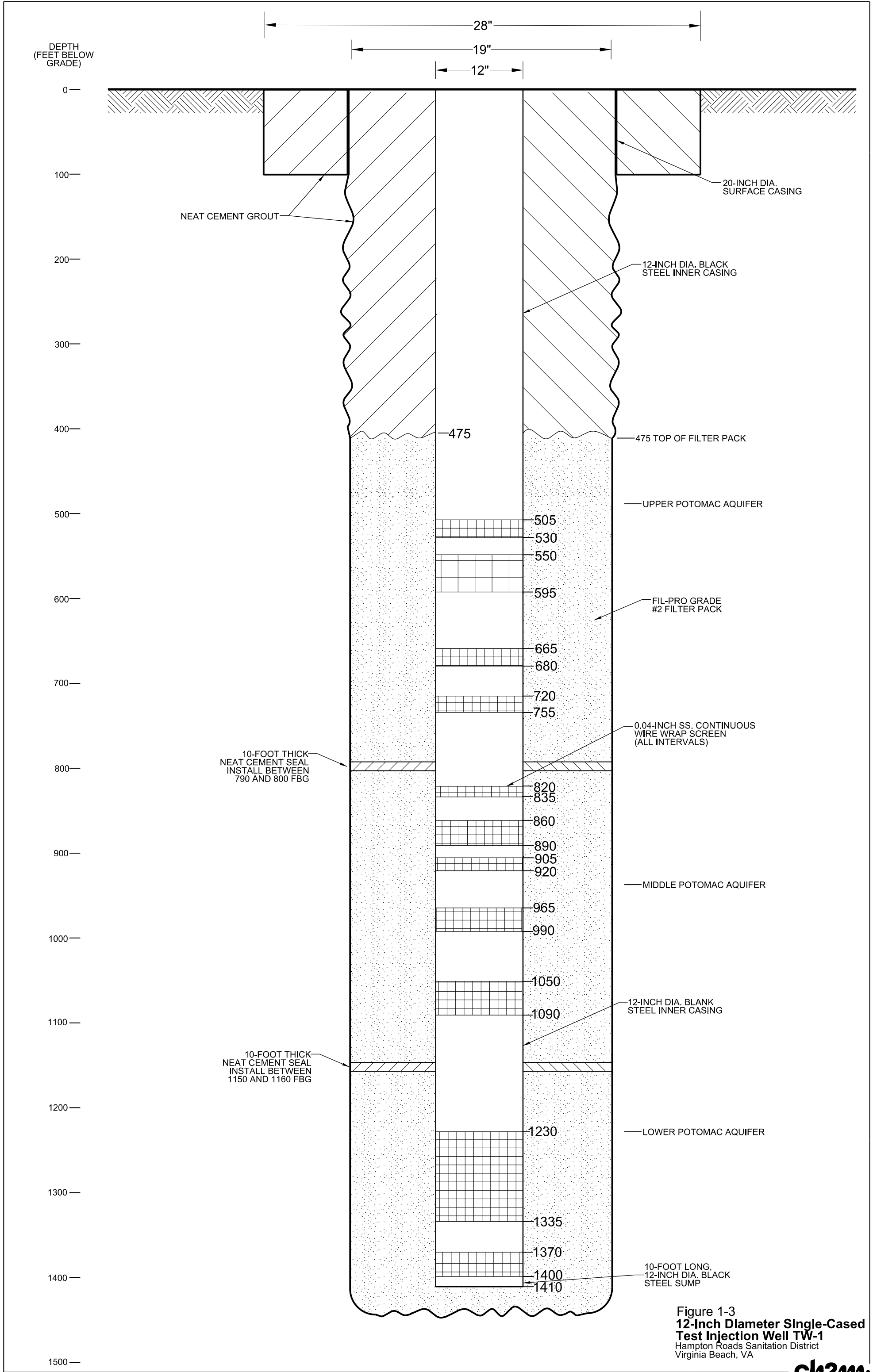


Figure 1-3
**12-Inch Diameter Single-Cased
Test Injection Well TW-1**
Hampton Roads Sanitation District
Virginia Beach, VA

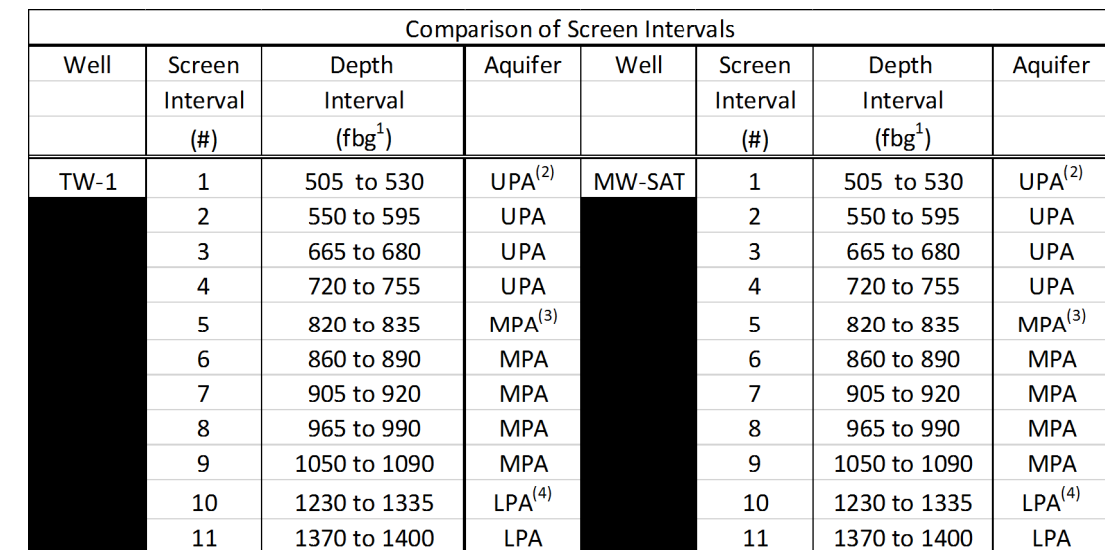


Figure 1-4
6-Inch Diameter Single-Cased
Monitoring Well MW-SAT and
FLUTe Sampling System
Hampton Roads Sanitation District
Virginia Beach, VA

Although HRSD plans on conducting MAR operations at 700 gallons per minute (gpm), TW-1 will contain a manufactured downhole valve that will accommodate adjusting the recharge to lower rates. The selected valve will work on a sliding sleeve concept, and will be mounted below the pump. Closing the valve backs water up the pump column, preventing pulling a vacuum at lowered recharge rates, and causing the entrainment of air in recharge water.

The downhole valve will accommodate recharging at lower rates for the first two weeks of MAR operations, while progressively increasing the rate to 700 gpm. This incremental approach to initiating recharge will protect clay minerals conditioned with the aluminum chloride solution from the effects of sudden, elevated exit velocities. Moreover, the downhole valve allows greater flexibility in responding to changing injectivity, if reductions in the recharge rate are required. The valve could also prove useful if HRSD wishes to conduct research at the SWIFTRC after the demonstration project ends and discharge water at lower rates.

To maximize mechanical energy on the shallowest well screens, HRSD will set the pump in TW-1 to 300 feet below grade (fbg), and run backflushing events at rates approaching 1,400 gpm, twice the recharge rate. The elevated rate optimizes the removal of particulates accumulating in the screen and filter pack during MAR operations. A 1 ¼-inch diameter poly-ethylene tube installed from the ground surface to the top of the pump, will allow installing a pressure transducer to measure and automatically record static, injection, and backflushing water levels during MAR operations. The tube will also facilitate manually measuring water levels with an electrical transducer.

The wellhead for TW-1 will consist of 8-inch diameter piping with automated isolation valves for conveying recharge and backflush water. Wellhead piping will contain a bi-directional electromagnetic flowmeter allowing recharging and backflushing TW-1 through the same piping. The piping design accommodates backflushing TW-1 to an effluent holding pond or a drain in the pump station. A pressure sustaining valve will protect the pump when backflushing to the effluent holding pond. The wellhead piping will contain four air relief valves to prevent air entrainment during MAR operations.

1.2 Multi-Aquifer Monitoring Well

MW-SAT will be located only 50 feet from TW-1 and will support evaluating the aquifer response, both hydraulic and water quality, to recharge from TW-1. Moreover, sampling at MW-SAT will support HRSD's field-scale soil aquifer treatment (SAT) study to assess attenuation of specific constituents during migration in the PAS.

MW-SAT will consist of a 6-inch diameter carbon steel casing and 380 feet of stainless steel, continuous wire wrap screen extending to 1,410 fbg, the same depth as TW-1. The eleven screen zones in MW-SAT will match the same intervals in TW-1 to the greatest extent practical.

After installing and developing MW-SAT, a flexible liner, discrete-interval sampling system manufactured by FLUTe (Figure 1-4) will be installed in the casing and screen assembly. The sampling system will consist of eleven sampling ports coinciding with each well screen. Sample tubing extending from each port will run to the ground surface and into the SWIFTRC where HRSD can measure field chemistry and collect samples for laboratory analysis from the depth discrete intervals (Figure 1-5). The system will also contain three pressure transducers to measure and record water levels in the upper, middle and lower zones of the PAS.

Nitrogen gas from canisters mounted on the exterior wall of the pilot area will drive sampling and purging. Operators will control purging and sampling from a three-way valve mounted on a panel in the pilot area of the SWIFTRC (Figure 1-6). To offer better flexibility, three manifolds will separate the gas and sampling tubing by aquifer (Upper, Middle, and Lower Potomac Aquifers). Recharge may reach the deeper screens in TW-1 much later than the upper screens, and so may not require the same sampling frequency.

MW-SAT will serve multiple, important roles in monitoring the hydraulic and geochemical response to MAR operations in the PAS. First, monitoring at MW-SAT will support characterizing hydrodynamic factors (advection, dispersion, diffusion, mixing, etc.) influencing solute transport in the PAS. MW-SAT will also serve as a station to evaluate SAT of selected trace organic compounds including trihalomethanes, haloacetic acids (HAA), contaminants of emerging concern (CEC), *N*-Nitrosodimethylamine (NDMA), etc., along with the leaching of arsenic from reactive metal bearing minerals, and residual aluminum for the clay conditioning treatments.

1.3 Conventional Monitoring Wells

MW-UPA, MW-MPA, and MW-LPA will be situated along a line at distances of 400, 450, and 500 feet south of TW-1 (Figure 1-2). The conventional monitoring wells consist of 6-inch diameter black steel casing with stainless steel, continuous wire wrap screens set against the same sand intervals as encountered in TW-1 (Figure 1-76). MW-UPA and MW-MPA will contain two and three screens, respectively, while MW-LPA contains two screens, with all totaling between 120 and 135 feet. Each monitoring well will contain a pressure transducer that measures and records water levels to the SWIFTRC SCADA system.

Each well will contain a 4-inch diameter sampling pump capable of purging water at flow rates up to 5 gpm. The pumping equipment will allow operators to purge well volumes prior to sampling, by running the pumps continuously during periods of higher sampling frequency. Piping from the pumps will run to the laboratory located at the SWIFTRC and discharge to a common sampling sink.

Once MAR operations start in earnest (700 gpm), around 100 days should elapse before recharge water will reach the well gallery, roughly 400 to 500 feet south of TW-1. At 95 days after starting operations, operators would turn on the pumps and let them run continuously until recharge passes the gallery. Running the pumps continuously at 2 gpm will prevent the discharge from exceeding the Nansemond Wastewater Treatment Plant (WWTP) permitted withdrawal threshold of 300,000 gallons per month, while still providing representative samples from each of the 11 intervals.

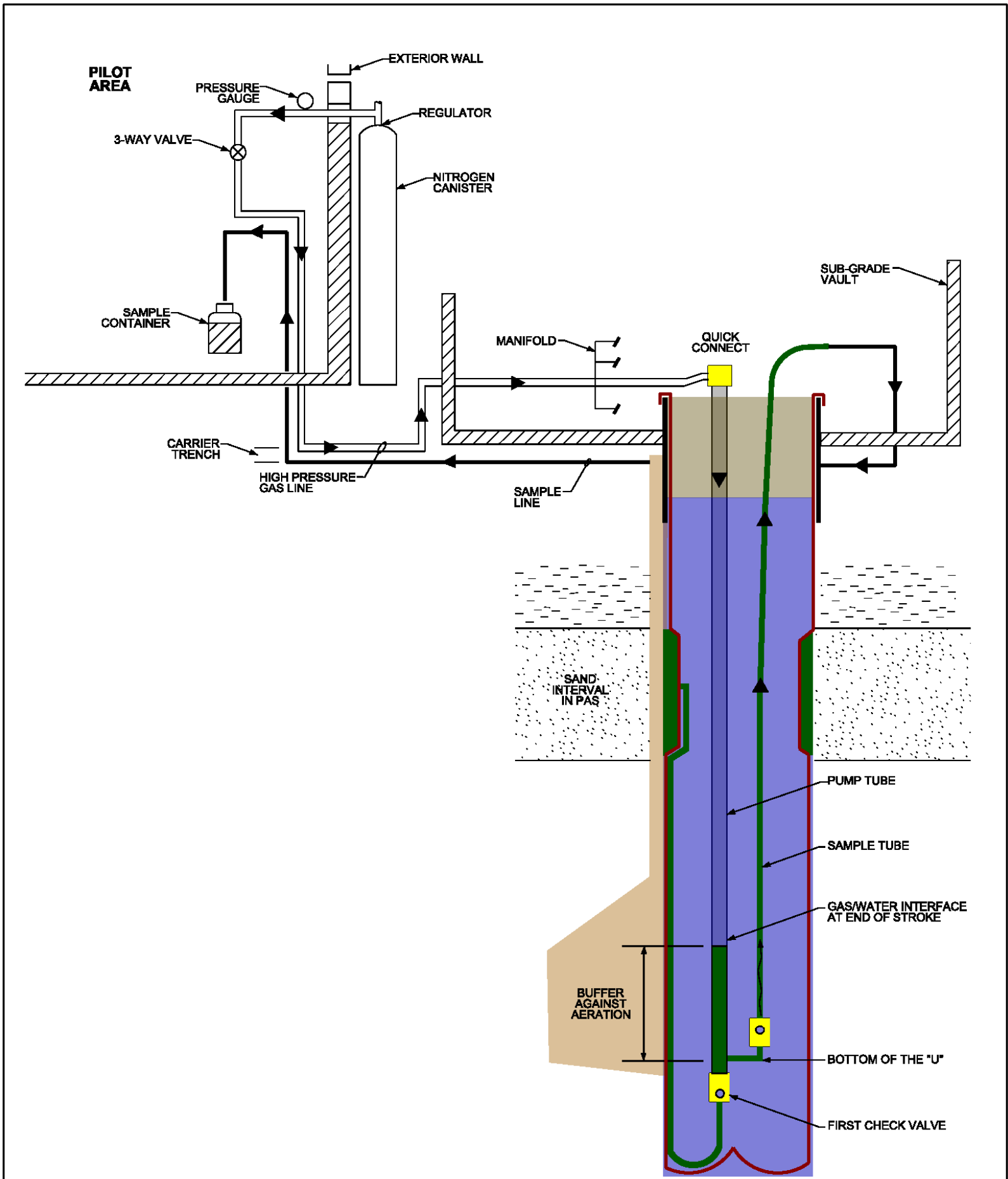


Figure 1-5
Conceptual Diagram of FLUTE Sampling
System Focusing on Single Gas and Sample Line
Hampton Roads Sanitation District
Virginia Beach, VA

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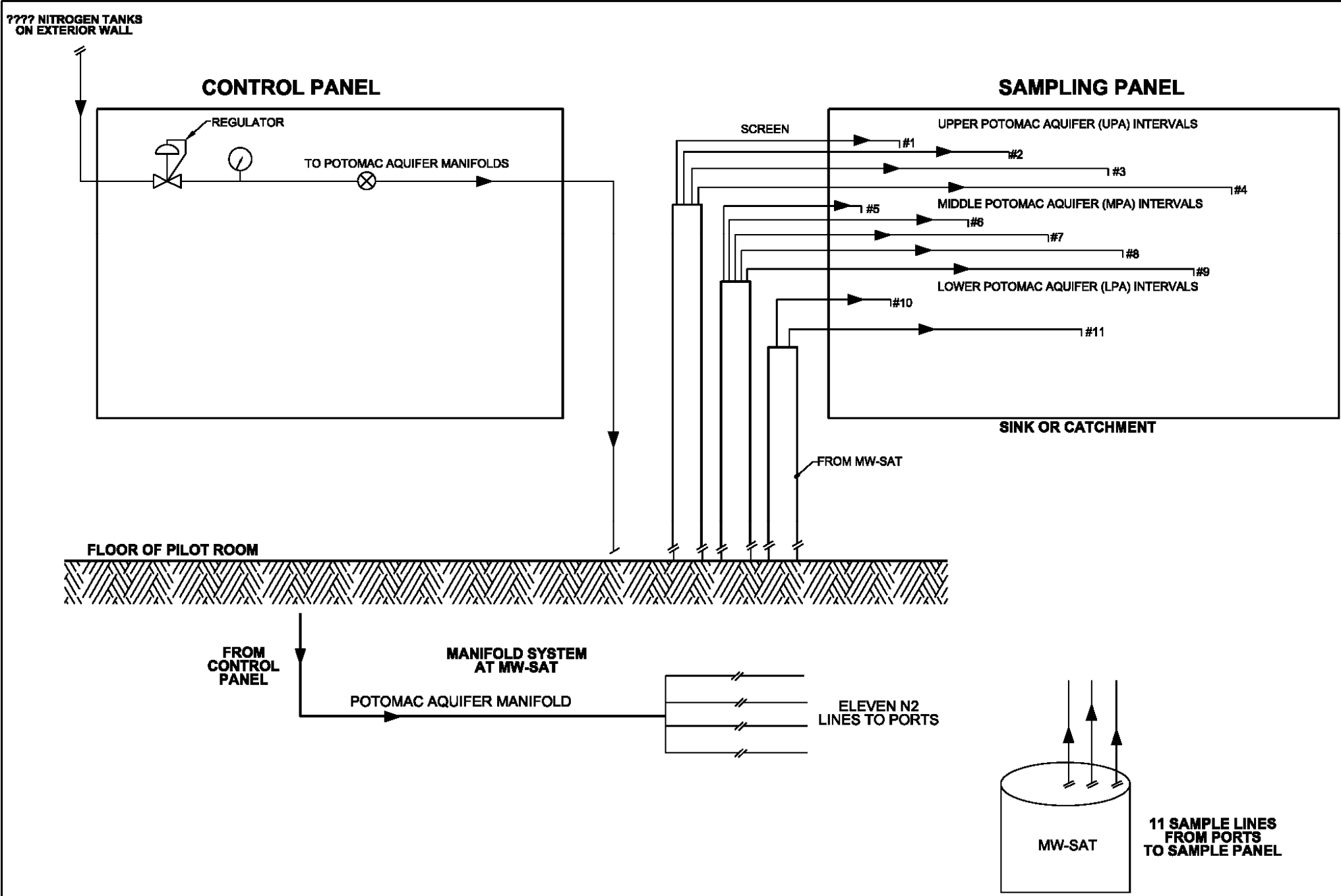
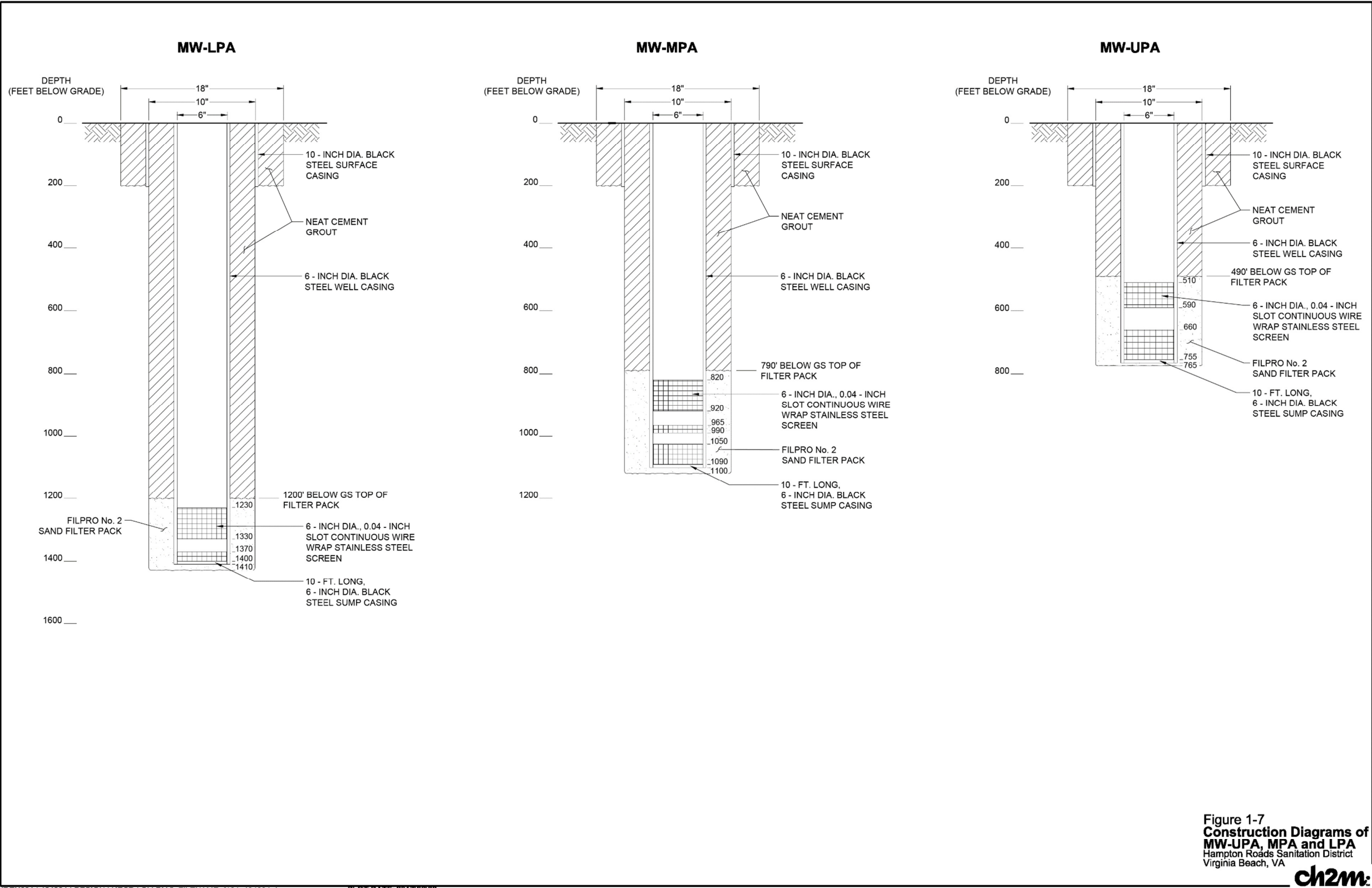


Figure 1-6
Schematic of Panels and Connectivity
Hampton Roads Sanitation District
Virginia Beach, VA



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Monitoring Plan

This section describes the hydraulic and water quality monitoring criteria critical to the success of the SWIFTRC MAR, including the following:

- Finished water -> Recharge water
- TW-1
- MW-SAT
- MW-UPA and MW-MPA
- MW-LPA

In addition to monitoring chemical reactions in the Potomac Aquifer system (PAS), by collecting samples periodically after the recharge front passes the monitoring wells, SWIFTRC's sampling approach will also account for acclimation of saprophytic microorganisms with recharge water in the aquifers.

2.1 SWIFTRC Finished Water

SWIFT Water will continually discharge into a sample sink in the SWIFTRC laboratory and will be continuously monitored by online analyzers for temperature, pH, turbidity, specific conductivity, and dissolved oxygen (DO). Attachment B of the UIC Inventory details the samples that HRSD will collect for SWIFT Water regulatory compliance and to indicate treatment efficacy of trace contaminants. Tables 2-1 provides a full sampling plan of the finished water.

Table 2-1. SWIFTRC Regulatory and Process Monitoring Plan

HRSD SWIFT Research Center Regulatory and Process Monitoring Plan ¹									
Sample Location and Frequency (Regulated parameters for specific compliance points noted in bold, italic font)									
Parameter	NP Influent	SWIFTRC Influent	Floc/Sed Effluent	Ozone Effluent	BAF IFE	BAF CFE	GAC CE	Tasting Tank	SWIFT Water
<i>Regulatory Parameters</i>									
Total Nitrogen		Weekly			Monthly		Monthly		<i>Daily</i>
Nitrate (NO ₃ -N) (SDWA PMCL)		Weekly			Monthly		Monthly		<i>Daily</i>
Nitrite-N (SDWA PMCL)		Weekly			Monthly		Monthly		<i>Daily</i>
Turbidity (SDWA PMCL)					Continuous²	Continuous²			
TOC		Weekly	3x/week		Monthly	3x/week	Continuou		<i>3x/week</i>
Total Coliform (SDWA PMCL)		Weekly							<i>Daily</i>
E. coli (SDWA PMCL)		Weekly							<i>Weekly</i>
Bromate (SDWA PMCL)				Daily					<i>Weekly</i>
Haloacetic acids (HAA5) (SDWA PMCL)									<i>Monthly</i>
Total trihalomethanes (SDWA PMCL)									<i>Monthly</i>
pH									<i>Continuous</i>
TDS									<i>Monthly</i>
<i>Remaining EPA Primary MCLs</i>									
Microorganisms									
Cryptosporidium	Quarterly	Quarterly							<i>Quarterly</i>
Giardia lamblia	Quarterly	Quarterly							<i>Quarterly</i>
Legionella		Quarterly							<i>Quarterly</i>
<i>Disinfection Byproducts</i>									
Chlorite	Monthly	Monthly							<i>Monthly</i>
<i>Disinfectants³</i>									
Chloramines (as Cl ₂)									<i>Continuous⁴</i>

Table 2-1. SWIFTRC Regulatory and Process Monitoring Plan

HRSD SWIFT Research Center Regulatory and Process Monitoring Plan ¹									
Sample Location and Frequency (Regulated parameters for specific compliance points noted in bold, italic font)									
Parameter	NP Influent	SWIFTRC Influent	Floc/Sed Effluent	Ozone Effluent	BAF IFE	BAF CFE	GAC CE	Tasting Tank	SWIFT Water
Chlorine (as Cl ₂)								As needed	<i>Continuous</i> ⁴
<i>Inorganic Chemicals</i>									
Antimony, Total	Monthly	Monthly							<i>Monthly</i>
Arsenic, Total	Monthly	Monthly							<i>Monthly</i>
Asbestos	Monthly	Monthly							<i>Monthly</i>
Barium, Total	Monthly	Monthly							<i>Monthly</i>
Beryllium, Total	Monthly	Monthly							<i>Monthly</i>
Cadmium, Total	Monthly	Monthly							<i>Monthly</i>
Chromium, Total	Monthly	Monthly							<i>Monthly</i>
Copper, Total	Monthly	Monthly							<i>Monthly</i>
Cyanide, Total	Monthly	Monthly							<i>Monthly</i>
Fluoride	Monthly	Monthly							<i>Monthly</i>
Lead, Total	Monthly	Monthly							<i>Monthly</i>
Mercury, Total	Monthly	Monthly							<i>Monthly</i>
Selenium, Total	Monthly	Monthly							<i>Monthly</i>
Thallium, Total	Monthly	Monthly							<i>Monthly</i>
<i>Organic Chemicals</i>									
Acrylamide	Monthly	Monthly							<i>Monthly</i>
Alachlor	Monthly	Monthly							<i>Monthly</i>
Atrazine	Monthly	Monthly							<i>Monthly</i>
Benzene	Monthly	Monthly							<i>Monthly</i>
Benzo(a)pyrene (PAHs)	Monthly	Monthly							<i>Monthly</i>

Table 2-1. SWIFTRC Regulatory and Process Monitoring Plan

HRSD SWIFT Research Center Regulatory and Process Monitoring Plan ¹									
Sample Location and Frequency (Regulated parameters for specific compliance points noted in bold, italic font)									
Parameter	NP Influent	SWIFTRC Influent	Floc/Sed Effluent	Ozone Effluent	BAF IFE	BAF CFE	GAC CE	Tasting Tank	SWIFT Water
Carbofuran	Monthly	Monthly							<i>Monthly</i>
Carbon Tetrachloride	Monthly	Monthly							<i>Monthly</i>
Chlordane	Monthly	Monthly							<i>Monthly</i>
Chlorobenzene	Monthly	Monthly							<i>Monthly</i>
2,4-D	Monthly	Monthly							<i>Monthly</i>
Dalapon	Monthly	Monthly							<i>Monthly</i>
1,2-dibromo-3-chloropropane (DBCP)	Monthly	Monthly							<i>Monthly</i>
1,2-Dichlorobenzene (o-dichlorobenzene)	Monthly	Monthly							<i>Monthly</i>
1,4-Dichlorobenzene (p-dichlorobenzene)	Monthly	Monthly							<i>Monthly</i>
1,2-Dichloroethane	Monthly	Monthly							<i>Monthly</i>
1,1-Dichloroethylene	Monthly	Monthly							<i>Monthly</i>
cis-1,2-Dichloroethene	Monthly	Monthly							<i>Monthly</i>
trans-1,2-Dichloroethene	Monthly	Monthly							<i>Monthly</i>
Dichloromethane (Methylene chloride)	Monthly	Monthly							<i>Monthly</i>
1,2-Dichloropropane	Monthly	Monthly							<i>Monthly</i>
Di(2-ethylhexyl) adipate	Monthly	Monthly							<i>Monthly</i>
Di(2-ethylhexyl) phthalate	Monthly	Monthly							<i>Monthly</i>
Dinoseb	Monthly	Monthly							<i>Monthly</i>
Dioxin (2,3,7,8-TCDD)	Monthly	Monthly							<i>Monthly</i>
Diquat	Monthly	Monthly							<i>Monthly</i>

Table 2-1. SWIFTRC Regulatory and Process Monitoring Plan

HRSD SWIFT Research Center Regulatory and Process Monitoring Plan ¹									
Sample Location and Frequency (Regulated parameters for specific compliance points noted in bold, italic font)									
Parameter	NP Influent	SWIFTRC Influent	Floc/Sed Effluent	Ozone Effluent	BAF IFE	BAF CFE	GAC CE	Tasting Tank	SWIFT Water
Endothall	Monthly	Monthly							<i>Monthly</i>
Endrin	Monthly	Monthly							<i>Monthly</i>
Epichlorohydrin	Monthly	Monthly							<i>Monthly</i>
Ethylbenzene	Monthly	Monthly							<i>Monthly</i>
Ethylene dibromide (EDB)	Monthly	Monthly							<i>Monthly</i>
Glyphosate	Monthly	Monthly							<i>Monthly</i>
Heptachlor	Monthly	Monthly							<i>Monthly</i>
Heptachlor Epoxide	Monthly	Monthly							<i>Monthly</i>
Hexachlorobenzene	Monthly	Monthly							<i>Monthly</i>
Hexachlorocyclopentadiene	Monthly	Monthly							<i>Monthly</i>
Lindane (Gamma-BHC)	Monthly	Monthly							<i>Monthly</i>
Methoxychlor	Monthly	Monthly							<i>Monthly</i>
Oxamyl (Vydate)	Monthly	Monthly							<i>Monthly</i>
Polychlorinated biphenyls	Monthly	Monthly							<i>Monthly</i>
AR1016	Monthly	Monthly							<i>Monthly</i>
AR1221	Monthly	Monthly							<i>Monthly</i>
AR1232	Monthly	Monthly							<i>Monthly</i>
AR1242	Monthly	Monthly							<i>Monthly</i>
AR1248	Monthly	Monthly							<i>Monthly</i>
AR1254	Monthly	Monthly							<i>Monthly</i>
AR1260	Monthly	Monthly							<i>Monthly</i>
Pentachlorophenol	Monthly	Monthly							<i>Monthly</i>

Table 2-1. SWIFTRC Regulatory and Process Monitoring Plan

HRSD SWIFT Research Center Regulatory and Process Monitoring Plan ¹									
Sample Location and Frequency (Regulated parameters for specific compliance points noted in bold, italic font)									
Parameter	NP Influent	SWIFTRC Influent	Floc/Sed Effluent	Ozone Effluent	BAF IFE	BAF CFE	GAC CE	Tasting Tank	SWIFT Water
Picloram	Monthly	Monthly							<i>Monthly</i>
Simazine	Monthly	Monthly							<i>Monthly</i>
Styrene	Monthly	Monthly							<i>Monthly</i>
Tetrachloroethene	Monthly	Monthly							<i>Monthly</i>
Toluene	Monthly	Monthly							<i>Monthly</i>
Toxaphene	Monthly	Monthly							<i>Monthly</i>
2,4,5-TP (Silvex)	Monthly	Monthly							<i>Monthly</i>
1,2,4-Trichlorobenzene	Monthly	Monthly							<i>Monthly</i>
1,1,1-Trichloroethane	Monthly	Monthly							<i>Monthly</i>
1,1,2-Trichloroethane	Monthly	Monthly							<i>Monthly</i>
Trichloroethylene	Monthly	Monthly							<i>Monthly</i>
Vinyl Chloride	Monthly	Monthly							<i>Monthly</i>
Xylene, Total	Monthly	Monthly							<i>Monthly</i>
Radionuclides									
Alpha particles (picocuries per liter [pCi/L])		Monthly							<i>Monthly</i>
Beta particles and photon emitters (pCi/L)		Monthly							<i>Monthly</i>
Radium 226 (pCi/L)		Monthly							<i>Monthly</i>
Radium 228 (pCi/L)		Monthly							<i>Monthly</i>
Uranium (µg/L)		Monthly							<i>Monthly</i>
Strontium-90 ⁵		Monthly							<i>Monthly</i>
Tritium ⁵		Monthly							<i>Monthly</i>

Table 2-1. SWIFTRC Regulatory and Process Monitoring Plan

HRSD SWIFT Research Center Regulatory and Process Monitoring Plan ¹									
Sample Location and Frequency (Regulated parameters for specific compliance points noted in bold, italic font)									
Parameter	NP Influent	SWIFTRC Influent	Floc/Sed Effluent	Ozone Effluent	BAF IFE	BAF CFE	GAC CE	Tasting Tank	SWIFT Water
<i>Virginia Groundwater Protection Standards</i>									
Aldrin/Dieldrin	Monthly	Monthly							<i>Monthly</i>
DDT	Monthly	Monthly							<i>Monthly</i>
Kepone	Monthly	Monthly							<i>Monthly</i>
Mirex	Monthly	Monthly							<i>Monthly</i>
Phenols	Monthly	Monthly							<i>Monthly</i>
<i>Non-regulatory Parameters</i>									
<i>Performance Indicators</i>									
<i>Public Health Indicators</i>									
1,4-dioxane	Quarterly	Quarterly							Quarterly
17- β -estradiol	Quarterly	Quarterly							Quarterly
DEET	Quarterly	Quarterly							Quarterly
Ethinyl estradiol	Quarterly	Quarterly							Quarterly
NDMA	Quarterly	Quarterly		Weekly		Weekly			Quarterly
Perchlorate	Quarterly	Quarterly							Quarterly
PFOA + PFOS	Quarterly	Quarterly							Quarterly
tris(2-carboxyethyl)phosphine (TCEP)	Quarterly	Quarterly							Quarterly
<i>Treatment Efficacy Indicators</i>									
Cotinine	Quarterly	Quarterly							Quarterly
Primidone	Quarterly	Quarterly							Quarterly
Phenytoin	Quarterly	Quarterly							Quarterly
Meprobamate	Quarterly	Quarterly							Quarterly

Table 2-1. SWIFTRC Regulatory and Process Monitoring Plan

HRSD SWIFT Research Center Regulatory and Process Monitoring Plan ¹									
Sample Location and Frequency (Regulated parameters for specific compliance points noted in bold, italic font)									
Parameter	NP Influent	SWIFTRC Influent	Floc/Sed Effluent	Ozone Effluent	BAF IFE	BAF CFE	GAC CE	Tasting Tank	SWIFT Water
Atenolol	Quarterly	Quarterly							Quarterly
Carbamazepine	Quarterly	Quarterly							Quarterly
Estrone	Quarterly	Quarterly							Quarterly
Sucralose	Quarterly	Quarterly							Quarterly
Triclosan	Quarterly	Quarterly							Quarterly
<i>Non-regulatory Parameters with Aquifer Compatibility Focus</i>									
Oxidation-Reduction Potential									Monthly
Specific Conductivity									Monthly
Dissolved Oxygen									Monthly
Temperature									Monthly
Chloride, field									Monthly
Iron, field (ferrous as Fe ²⁺)									Monthly
Iron, Total, field									Monthly
Alkalinity, field (as CaCO ₃)									Monthly
Aluminum, dissolved									Monthly
Aluminum, total									Monthly
Arsenic, dissolved									Monthly
Iron, dissolved									Monthly
Iron, total									Monthly
Manganese, dissolved									Monthly
Manganese, total									Monthly
Magnesium, total									Monthly

Table 2-1. SWIFTRC Regulatory and Process Monitoring Plan

HRSD SWIFT Research Center Regulatory and Process Monitoring Plan ¹									
Sample Location and Frequency (Regulated parameters for specific compliance points noted in bold, italic font)									
Parameter	NP Influent	SWIFTRC Influent	Floc/Sed Effluent	Ozone Effluent	BAF IFE	BAF CFE	GAC CE	Tasting Tank	SWIFT Water
Potassium, total									Monthly
Sodium, total									Monthly
Calcium, total									Monthly
Sulfate									Monthly
Chloride									Monthly
Alkalinity									Monthly
Total Kjeldahl Nitrogen ⁶		Weekly			Monthly		Monthly		<i>Daily</i>
Ammonia as N									Monthly
Total Phosphorus									Monthly
Orthophosphate as P									Monthly
Fluoride									Monthly
Silica as SiO ₂									Monthly
Dissolved Organic Carbon									Monthly
Total Suspended Solids									Monthly
Hardness, Total									Monthly
Bypass Filtering Testing									Monthly
Microfouling Index Testing									Monthly
<i>Additional monitoring with research focus (TBD by SWIFT Monitoring Program)</i>									
<i>Pathogens and Pathogen Indicators</i>									
Adenovirus	Quarterly	Quarterly							Quarterly
Campylobacter	Quarterly	Quarterly							Quarterly

Table 2-1. SWIFTRC Regulatory and Process Monitoring Plan

HRSD SWIFT Research Center Regulatory and Process Monitoring Plan ¹									
Sample Location and Frequency (Regulated parameters for specific compliance points noted in bold, italic font)									
Parameter	NP Influent	SWIFTRC Influent	Floc/Sed Effluent	Ozone Effluent	BAF IFE	BAF CFE	GAC CE	Tasting Tank	SWIFT Water
Norovirus GI	Quarterly	Quarterly							Quarterly
Norovirus GII	Quarterly	Quarterly							Quarterly
Enterovirus	Quarterly	Quarterly							Quarterly
Rotavirus	Quarterly	Quarterly							Quarterly
Pepper Mild Mottle Virus	Quarterly	Quarterly							Quarterly
Male Specific Coliphages	Quarterly	Quarterly							Quarterly
Somatic Coliphages	Quarterly	Quarterly							Quarterly
<i>CCL4& UCMR4 not included in above routine monitoring (parameters with commercially available analytical method)</i>									
Total microcystin	Quarterly	Quarterly							Quarterly
Microcystin-LR	Quarterly	Quarterly							Quarterly
Anatoxin-a	Quarterly	Quarterly							Quarterly
Cylindrospermopsin	Quarterly	Quarterly							Quarterly
Germanium	Quarterly	Quarterly							Quarterly
Chlorpyrifos	Quarterly	Quarterly							Quarterly
Total permethrin (cis- and trans-)	Quarterly	Quarterly							Quarterly
Bromochloroacetic acid	Quarterly	Quarterly							Quarterly
Bromodichloroacetic acid	Quarterly	Quarterly							Quarterly
Dibromochloroacetic acid	Quarterly	Quarterly							Quarterly
Tribromoacetic acid	Quarterly	Quarterly							Quarterly
Quinoline	Quarterly	Quarterly							Quarterly
Bromide	Quarterly	Quarterly							Quarterly

Table 2-1. SWIFTRC Regulatory and Process Monitoring Plan

HRSD SWIFT Research Center Regulatory and Process Monitoring Plan ¹									
Sample Location and Frequency (Regulated parameters for specific compliance points noted in bold, italic font)									
Parameter	NP Influent	SWIFTRC Influent	Floc/Sed Effluent	Ozone Effluent	BAF IFE	BAF CFE	GAC CE	Tasting Tank	SWIFT Water
1,1-dichloroethane	Quarterly	Quarterly							Quarterly
1,1,2,2-trichloroethane	Quarterly	Quarterly							Quarterly
1,2,3-trichloropropane	Quarterly	Quarterly							Quarterly
1,3-butadiene	Quarterly	Quarterly							Quarterly
Acrolein	Quarterly	Quarterly							Quarterly
Aniline	Quarterly	Quarterly							Quarterly
Chlorate	Quarterly	Quarterly							Quarterly
Chloromethane	Quarterly	Quarterly							Quarterly
Cobalt	Quarterly	Quarterly							Quarterly
Diuron	Quarterly	Quarterly							Quarterly
Equilin	Quarterly	Quarterly							Quarterly
Erythromycin	Quarterly	Quarterly							Quarterly
Estriol	Quarterly	Quarterly							Quarterly
Formaldehyde	Quarterly	Quarterly							Quarterly
HCFC-22 (Chlorodifluoromethane)	Quarterly	Quarterly							Quarterly
Halon 1011 (bromochloromethane)	Quarterly	Quarterly							Quarterly
Hexane	Quarterly	Quarterly							Quarterly
Methanol	Quarterly	Quarterly							Quarterly
Methyl bromide	Quarterly	Quarterly							Quarterly
Methyl tert-butyl ether (MTBE)	Quarterly	Quarterly							Quarterly
Molybdenum	Quarterly	Quarterly							Quarterly
Nitrobenzene	Quarterly	Quarterly							Quarterly

Table 2-1. SWIFTRC Regulatory and Process Monitoring Plan

HRSD SWIFT Research Center Regulatory and Process Monitoring Plan ¹									
Sample Location and Frequency (Regulated parameters for specific compliance points noted in bold, italic font)									
Parameter	NP Influent	SWIFTRC Influent	Floc/Sed Effluent	Ozone Effluent	BAF IFE	BAF CFE	GAC CE	Tasting Tank	SWIFT Water
N-nitrosodiethylamine (NDEA)	Quarterly	Quarterly							Quarterly
N-nitroso-di-n-propylamine (NDPA)	Quarterly	Quarterly							Quarterly
N-nitrosodiphenylamine	Quarterly	Quarterly							Quarterly
N-nitrosopyrrolidine (NPYR)	Quarterly	Quarterly							Quarterly
Nonylphenol	Quarterly	Quarterly							Quarterly
Norethindrone	Quarterly	Quarterly							Quarterly
Permethrin	Quarterly	Quarterly							Quarterly
sec-Butylbenzene	Quarterly	Quarterly							Quarterly
Tellurium	Quarterly	Quarterly							Quarterly
Vanadium	Quarterly	Quarterly							Quarterly
<i>Additional analytes not included in UCMR4 or CCL4⁷</i>									
BDE-100	Quarterly	Quarterly							Quarterly
BDE-153	Quarterly	Quarterly							Quarterly
BDE-154	Quarterly	Quarterly							Quarterly
BDE-183	Quarterly	Quarterly							Quarterly
BDE-209	Quarterly	Quarterly							Quarterly
BDE-28	Quarterly	Quarterly							Quarterly
BDE-47	Quarterly	Quarterly							Quarterly
BDE-99	Quarterly	Quarterly							Quarterly
Tris(2-chloroethyl) phosphate (TCPP)	Quarterly	Quarterly							Quarterly

Table 2-1. SWIFTRC Regulatory and Process Monitoring Plan

HRSD SWIFT Research Center Regulatory and Process Monitoring Plan ¹									
Sample Location and Frequency (Regulated parameters for specific compliance points noted in bold, italic font)									
Parameter	NP Influent	SWIFTRC Influent	Floc/Sed Effluent	Ozone Effluent	BAF IFE	BAF CFE	GAC CE	Tasting Tank	SWIFT Water
Tris(1,3-dichloro-2-propyl)phosphate (TDCPP)	Quarterly	Quarterly							Quarterly
Androstenedione	Quarterly	Quarterly							Quarterly
Estradiol	Quarterly	Quarterly							Quarterly
Estriol	Quarterly	Quarterly							Quarterly
Progesterone	Quarterly	Quarterly							Quarterly
Theobromine	Quarterly	Quarterly							Quarterly
1,7-Dimethylxanthine	Quarterly	Quarterly							Quarterly
Acesulfame-K	Quarterly	Quarterly							Quarterly
Butylparaben	Quarterly	Quarterly							Quarterly
Caffeine	Quarterly	Quarterly							Quarterly
Ethylparaben	Quarterly	Quarterly							Quarterly
Isobutylparaben	Quarterly	Quarterly							Quarterly
Methylparaben	Quarterly	Quarterly							Quarterly
Musk ketone	Quarterly	Quarterly							Quarterly
Propylparaben	Quarterly	Quarterly							Quarterly
Triclocarban (TCC)	Quarterly	Quarterly							Quarterly
Acetaminophen	Quarterly	Quarterly							Quarterly
Albuterol	Quarterly	Quarterly							Quarterly
Amoxicillin	Quarterly	Quarterly							Quarterly
Atenolol	Quarterly	Quarterly							Quarterly
Azithromycin	Quarterly	Quarterly							Quarterly

Table 2-1. SWIFTRC Regulatory and Process Monitoring Plan

HRSD SWIFT Research Center Regulatory and Process Monitoring Plan ¹									
Sample Location and Frequency (Regulated parameters for specific compliance points noted in bold, italic font)									
Parameter	NP Influent	SWIFTRC Influent	Floc/Sed Effluent	Ozone Effluent	BAF IFE	BAF CFE	GAC CE	Tasting Tank	SWIFT Water
Bendroflumethiazide	Quarterly	Quarterly							Quarterly
Bezafibrate	Quarterly	Quarterly							Quarterly
Butalbital	Quarterly	Quarterly							Quarterly
Carbadox	Quarterly	Quarterly							Quarterly
Carisoprodol	Quarterly	Quarterly							Quarterly
Chloramphenicol	Quarterly	Quarterly							Quarterly
Cimetidine	Quarterly	Quarterly							Quarterly
Clofibric acid	Quarterly	Quarterly							Quarterly
Dehydronifedipine	Quarterly	Quarterly							Quarterly
Diazepam	Quarterly	Quarterly							Quarterly
Diclofenac	Quarterly	Quarterly							Quarterly
Dilantin	Quarterly	Quarterly							Quarterly
Diltiazem	Quarterly	Quarterly							Quarterly
Flumequine	Quarterly	Quarterly							Quarterly
Fluoxetine	Quarterly	Quarterly							Quarterly
Galaxolide	Quarterly	Quarterly							Quarterly
Gemfibrozil	Quarterly	Quarterly							Quarterly
Ibuprofen	Quarterly	Quarterly							Quarterly
Iohexol	Quarterly	Quarterly							Quarterly
Iopromide	Quarterly	Quarterly							Quarterly
Ketoprofen	Quarterly	Quarterly							Quarterly
Keterolac	Quarterly	Quarterly							Quarterly

Table 2-1. SWIFTRC Regulatory and Process Monitoring Plan

HRSD SWIFT Research Center Regulatory and Process Monitoring Plan ¹									
Sample Location and Frequency (Regulated parameters for specific compliance points noted in bold, italic font)									
Parameter	NP Influent	SWIFTRC Influent	Floc/Sed Effluent	Ozone Effluent	BAF IFE	BAF CFE	GAC CE	Tasting Tank	SWIFT Water
Lidocaine	Quarterly	Quarterly							Quarterly
Lincomycin	Quarterly	Quarterly							Quarterly
Linuron	Quarterly	Quarterly							Quarterly
Lopressor	Quarterly	Quarterly							Quarterly
Meclofenamic acid	Quarterly	Quarterly							Quarterly
Naproxen	Quarterly	Quarterly							Quarterly
Nifedipine	Quarterly	Quarterly							Quarterly
Oxolinic acid	Quarterly	Quarterly							Quarterly
Pentoxifylline	Quarterly	Quarterly							Quarterly
Phenazone	Quarterly	Quarterly							Quarterly
Propazine	Quarterly	Quarterly							Quarterly
Sulfachloropyridazine	Quarterly	Quarterly							Quarterly
Sulfadiazine	Quarterly	Quarterly							Quarterly
Sulfadimethoxine	Quarterly	Quarterly							Quarterly
Sulfamerazine	Quarterly	Quarterly							Quarterly
Sulfamethazine	Quarterly	Quarterly							Quarterly
Sulfamethizole	Quarterly	Quarterly							Quarterly
Sulfamethoxazole	Quarterly	Quarterly							Quarterly
Sulfathiazole	Quarterly	Quarterly							Quarterly
Theophylline	Quarterly	Quarterly							Quarterly
Thiabendazole	Quarterly	Quarterly							Quarterly
Trimethoprim	Quarterly	Quarterly							Quarterly

Table 2-1. SWIFTRC Regulatory and Process Monitoring Plan

HRSD SWIFT Research Center Regulatory and Process Monitoring Plan ¹									
Sample Location and Frequency (Regulated parameters for specific compliance points noted in bold, italic font)									
Parameter	NP Influent	SWIFTRC Influent	Floc/Sed Effluent	Ozone Effluent	BAF IFE	BAF CFE	GAC CE	Tasting Tank	SWIFT Water
Warfarin	Quarterly	Quarterly							Quarterly
Bromacil	Quarterly	Quarterly							Quarterly
Chloridazon	Quarterly	Quarterly							Quarterly
Chlorotoluron	Quarterly	Quarterly							Quarterly
Cyanazine	Quarterly	Quarterly							Quarterly
Diaminochloro-atrazine (DACT)	Quarterly	Quarterly							Quarterly
Desethyl-atrazine (DEA)	Quarterly	Quarterly							Quarterly
Desisopropyl-atrazine (DIA)	Quarterly	Quarterly							Quarterly
Fenitrothion	Quarterly	Quarterly							Quarterly
Fipronil	Quarterly	Quarterly							Quarterly
Isoproturon	Quarterly	Quarterly							Quarterly
Kepone	Quarterly	Quarterly							Quarterly
Metazachlor	Quarterly	Quarterly							Quarterly
Sulfometuron, methyl	Quarterly	Quarterly							Quarterly

¹ All samples are collected as grabs unless denoted as "Continuous". 15-minute data will be reported for each continuous measurement.

² All in service turbidimeters will be verified with daily lab grabs. Both grab and 15 min turbidimeter data will be submitted for IFE and CFE. If a turbidimeter is out of service, unreliable or suspect, turbidity samples will be collected by grab for lab analysis every 4 hours.

³ ClO₂ not used for disinfection and therefore is not included in monitoring.

⁴ Continuous measurements of chlorine and chloramines will be confirmed with a daily grab.

⁵ Required by the Virginia Department of Health to determine vulnerability due to potential contribution from military bases.

⁶ TKN monitoring frequency to match TN monitoring frequency as TKN is needed for the calculation of TN. If HRSD sufficiently demonstrates comparability of the direct measurement of TN to VDH and DEQ satisfaction, TKN frequency will be reduced such that TKN will only be measured in the SWIFT Water on a monthly basis.

⁷ Additional parameters for research focus beyond the CCL4 and UCMR 4 parameters are subject to change based on occurrence data at the SWIFTRC and in secondary effluent at future SWIFT facilities.

2.1.1 Total Suspended Solids Loading to TW-1

In addition to the suite of laboratory analyses run on the SWIFT Water, the loading of total suspended solids (TSS) will be monitored using a Bypass Filtering Index (BFI) Testing and Micro-Fouling Index (MFI) testing techniques. Even the most highly treated water contains a small concentration of TSS that if left to accumulate in a MAR well can clog the screen, filter pack, and pore spaces in the borehole wall. The BFI and MFI testing methods offer techniques to characterize the rate of TSS loading to an MAR well to an accuracy of 0.001 milligrams per liter (mg/L), a corresponding annual clogging rate (Figure 2-1), and the filtrate necessary to determine the composition of materials that clog the BFI and MFI filters, and presumably the MAR well. Both BFI and MFI techniques closely resemble silt density index testing (ASTM D4189-95).

2.1.1.1 BFI Testing

BFI testing is performed through an apparatus situated across a pressure-reducing valve (PRV) on the wellhead or other piping (Figure 2-2). The inlet to the apparatus is situated upstream of the PRV with the outlet downstream. The BFI functions most effectively when the PRV causes a pressure drop of 30 pounds per square inch across the valve, and the apparatus hangs off the bottom of the piping, catching TSS migrating along the bottom of the pipe. At SWIFTRC, the BFI apparatus will be fed from a sample line directed to the laboratory that originates from a port on the wellhead piping located at the bottom of the wellhead piping, adjacent to TW-1.

The BFI filter element consists of a 10-cm long, spun polyester canister filter mounted in a housing located upstream of a totalizing flowmeter. The flowmeter will measure the flowrate and volume passing through the filter unit.

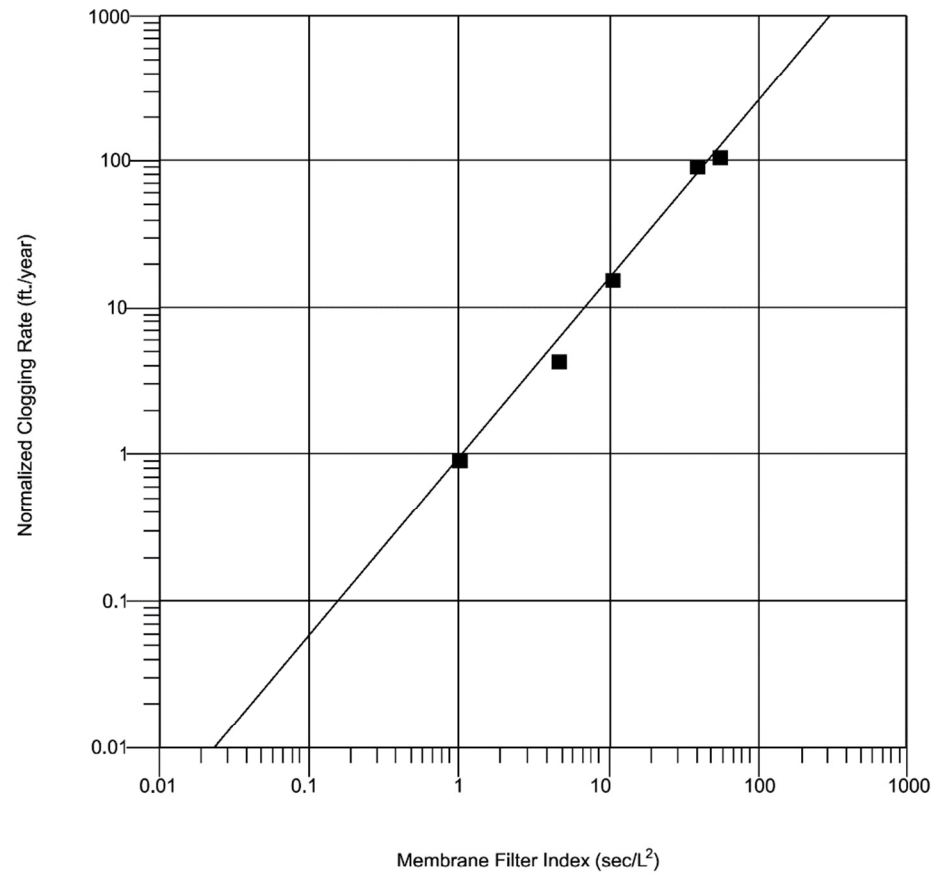
To initiate a test, a new filter element is weighed (dry) to the nearest 0.1 gram, and installed in the canister housing. After installing the filter, an operator will measure the flowrate through the flowmeter, daily, until the rate declines to approximately 20 percent of the original rate. The length of a single test can run from several days for water containing higher TSS to several months. The operator should also record the SWIFT Water temperature at the same time as the flowrate.

Upon reaching the reduced flowrate, the filter is removed, dried and weighed to the nearest 0.1 grams. A TSS concentration is calculated based of the difference in weights and flow volume through the filter apparatus. The flowrate measurements and totalized volumes are used to compute the BFI using a graphical technique. The BFI is calculated as the slope of a portion of the curve prepared from a graph of total volume and the time divided by the total volume (Figure 2-3).

To document TSS loading, BFI, and clogging rates over the duration of MAR operations, a new test should be initiated immediately after finishing the previous test.

2.1.1.2 MFI Testing

The MFI test procedure involves filtering SWIFT Water through a 47-millimeter (mm) diameter, 0.45-micrometer membrane filter at a constant pressure of 30 psi. MFI tests run through an apparatus consisting of tubing connected to a ball valve, pressure regulator, pressure gauge, and a 47-mm filter holder connected in series (Figure 2-4). The BFI apparatus will contain a hose bib for attaching the MFI device. Water passing through the apparatus is discharged to a 1000 ml graduated cylinder. The rate of discharge to the cylinder is measured with a stopwatch and recorded for selected volume increments.

**Legend**

■ Original Research

Source: Huisman and Olsthoorn, 1983
 Power Curve Fit $y = aX^b$
 $r = 0.987$
 $a = 0.617$ $b = 1.336$

Figure 2-1
Clogging Rate Based on MFI Index
 Hampton Roads Sanitation District
 Virginia Beach, VA

(DEN001 | 494884 | DESIGN | HRSD | CI | DLV) FILENAME: f136_494884.dgn PLOT DATE: 2017/05/02

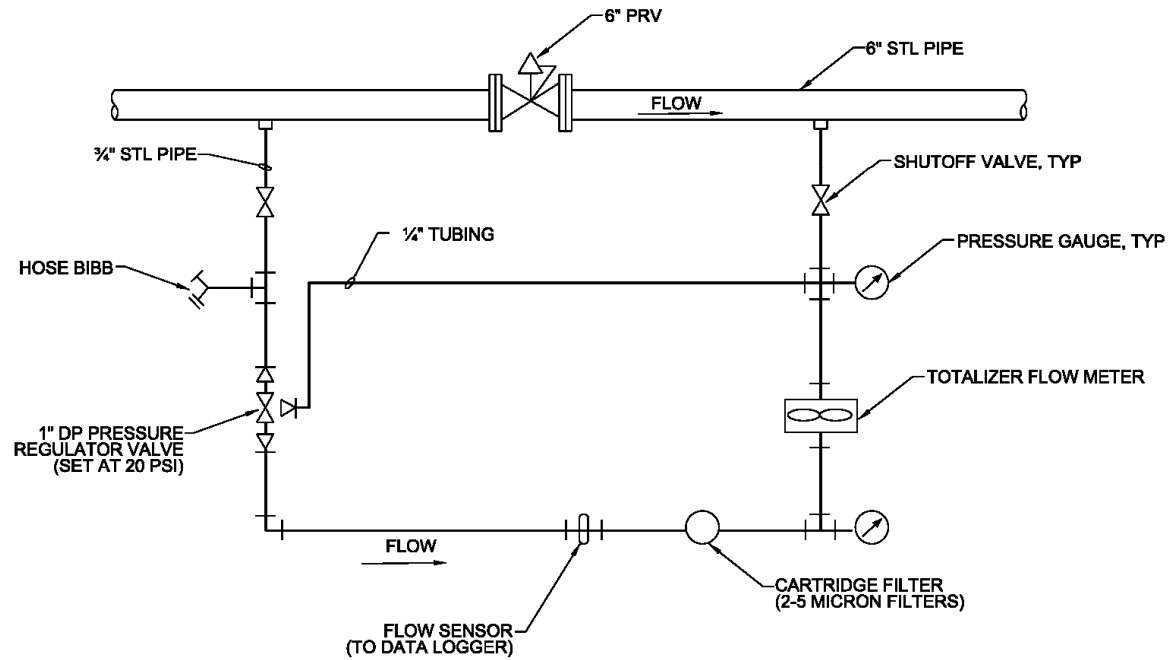


Figure 2-2
BFI Piping Schematic
 Hampton Roads Sanitation District
 Virginia Beach, VA

ch2m:

(DEN001 | 494884 | DESIGN | HRSD | CI | DLV) FILENAME: f132_494884.dgn PLOT DATE: 2017/05/03

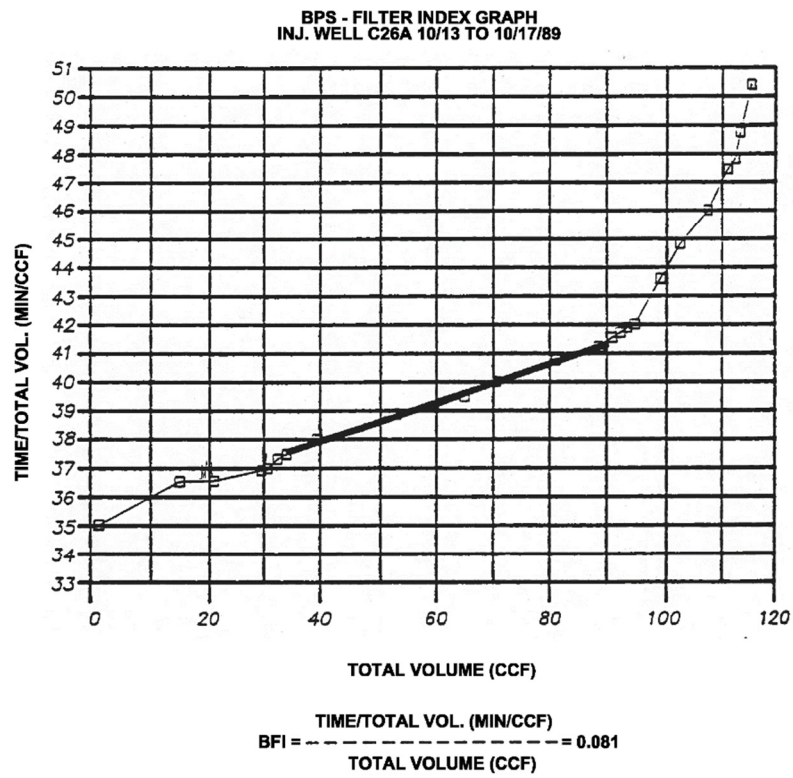


Figure 2-3
Typical Bypass Filter Graph
 Hampton Roads Sanitation District
 Virginia Beach, VA

ch2m:

(DEN001 | 494884 | DESIGN | HRSD | CI | DLV) FILENAME: f134_494884.dgn PLOT DATE: 2017/05/02

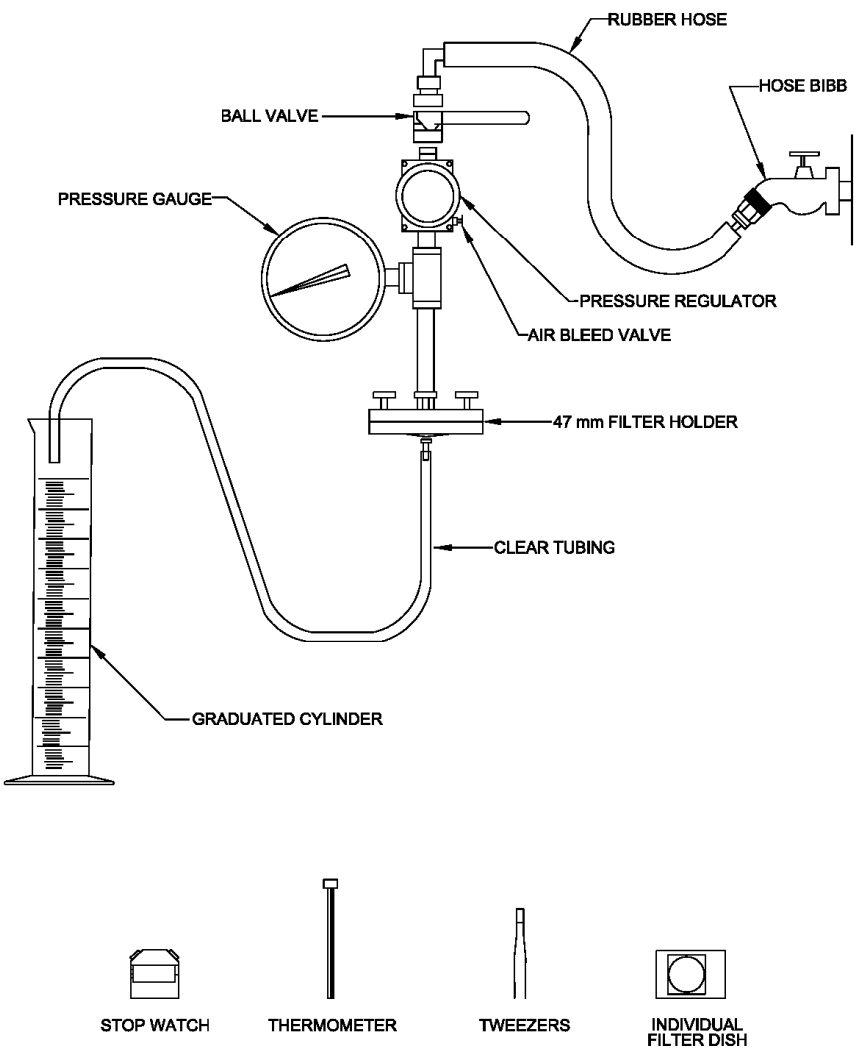


Figure 2-4
Illustration of Micro-Filter
Testing Equipment
Hampton Roads Sanitation District
Virginia Beach, VA



Similar to the BFI, tests are run until the flow rate through the filter falls to 20 percent of the original rate. Filters are weighed dry to the nearest 0.001 gram before and after the tests. The MFI correlates with the same annual clogging rate nomograph as the BFI tests. Three consecutive tests should be conducted monthly during MAR operations. Each test should last 60 to 90 minutes. TSS concentrations and the MFI is calculated in nearly the same manner as the BFI.

2.2 Managed Aquifer Recharge Well

Monitoring at TW-1 during MAR operations will be conducted to support operation of the well and will include injection rates, injection levels in the well, and pressure measurements in the pump column and annular space of the well. All measurements will be recorded continuously by the SWIFTRC distributed control system. Analyzing water level measurements and flowrates daily will help HRSD operators track the injectivity of TW-1.

A downhole valve manufactured by V-Smart, will control recharge rates in TW-1. During normal operations, HRSD will recharge TW-1 at 700 gpm. Yet, the downhole valve will accommodate recharging at lower rates for the first two weeks of MAR operations, while progressively increasing the rate to 700 gpm. This incremental approach to initiating recharge will protect clay minerals conditioned with the aluminum chloride solution from the effects of sudden, elevated exit velocities at TW-1.

Injectivity represents a hydraulic performance index defined by injection rate divided by draw-up in the well. The injectivity depends on the injection rate and the duration of MAR operations. To ensure the consistency and accuracy of injectivity values, the index is calculated from a data set collected at the same time each day. The injectivity monitoring will be performed to determine the rate at which the well is clogging and therefore will inform the frequency of backflushing of the well required to maintain efficient recharge operations.

Most systems operating MAR wells screened in the aquifers Northern and Middle Atlantic Coastal Plain Province backflush wells on a consistent frequency. The practice helps keep well screens and filter packs clean, by preventing the accumulation of TSS. Consistent operations also allow scheduling other activities in the MAR facility around backflushing events, while enabling easier tracking of injectivity and well pressures over time.

To preclude experiencing the drastic injectivity losses typically associated with starting a MAR well, backflushing will occur on a consistent, frequent, schedule such as three-times weekly for the first six months of operations. Only after establishing the conditions of service (injection rate, drawup, backflushing rate, drawdown, injectivity, TSS loading, BFI and MFI indices) for MAR operations at TW-1, will operators relax the backflushing schedule, and reduce the frequency.

2.2.1 Backflushing

Even the highest quality treated water contains small amounts of total suspended solids (TSS) that accumulate (clogging) in the screen and pores spaces of the sand filter pack and formation. Clogging reduces the permeability around the screen, filter pack, and aquifer proximal to the well (wellbore environment), resulting in higher injection levels while reducing injection capacity.

TW-1 will contain a vertical turbine pump capable of producing roughly 1,400 gpm, two times the recharge rate, allowing periodic well development (backflushing) during recharge. Backflushing entails temporarily shutting down recharge and turning on the well pump for a sufficient time to draw fine grained materials from the wellbore environment to the ground surface. After pumping an initial volume of turbid water, the discharge clears, and operations staff can turn off the pump and resume injection operations.

At TW-1, the time to complete a backflushing event should range from 50 to 65 minutes, depending the time required for the backflush effluent to clear. A backflushing event will start with turning off the recharge to TW-1, allowing 5 minutes for the water level to return to near static conditions, reconfiguring the wellhead valves, and then turning on the well pump. At a setting of 300 fbg and a backflushing rate approaching 1,400 gpm, the pump will generate good mechanical energy on the shallowest screens, while maximizing the removal of solids accumulating in the screens, filter pack, and at the borehole wall.

The time for water from the deepest screen interval at 1,400 fbg to reach the ground surface will take around 7 minutes when pumping at 1,400 gpm. Initial discharge from the screen intervals will exhibit elevated turbidity and sediment, but will diminish rapidly to levels below 10 nephelometric turbidity units (NTU). Achieving a turbidity of 10 NTU should take 20 to 30 minutes after observing the initial return from the screen. Operators can stop backflushing upon observing turbidity less than 10 NTU in the backflush effluent.

TW-1 should remain at static conditions for 10 minutes after turning the pump off so the pumping level can return to near static conditions, before resuming recharge. Starting recharge before water levels sufficiently recover can result in a strong hydraulic rebounding effect, where the injection level builds rapidly, but does not reflect clogging. Rebounding effects, following backflushing, often appear in MAR wells featuring long, intermittent screen intervals, like TW-1.

Resuming recharge will first entail flushing water to waste through the wellhead to remove sediments settling in the wellhead piping during backflushing. After discharge from the wellhead runs clear and free of sediments, recharge is resumed in the MAR well. Clearing the wellhead piping typically only takes 1 to 2 minutes.

Backflushing events can involve one to three pumping intervals. At nearly all sites, the first event produces the most notable results regarding the amount of solids removed and increased injectivity. Hydraulic benefits diminish after the first pumping event. Thus, a backflushing program involving a single pumping event, implemented at frequent intervals such as two to three times per week offers the best approach for maintaining the MAR well near peak hydraulic performance.

2.3 Multi-Aquifer Monitoring Well

MW-SAT, located only 50 feet from TW-1, will serve multiple roles during MAR operations at the SWIFTRC including:

- Measuring the hydraulic response in the three PAS aquifers at a distance less than one aquifer thickness away from TW-1.
- Characterizing hydrodynamic elements (advection, dispersion, diffusion, mechanical mixing etc.) of solute transport in the PAS system.
- Describing redox conditions at the interface between recharge and native groundwater.
- Helping determine the magnitude of cation exchange between the recharge and aquifer.
- Quantifying the attenuation and treatment/removal of major constituents in the recharge, including DO, nitrate, TKN, phosphorus, orthophosphate, total organic carbon (TOC), dissolved organic carbon (DOC), COD, and several others.
- Evaluating the migration of aluminum after in situ treatment of clay minerals around the wellbore to TW-1.
- Characterizing SAT of selected trace organic compounds such as trihalomethanes, HAAs, CECs and NDMA.

- Monitoring the leaching of undesirable metals from minerals in the PAS including iron, manganese, and arsenic.
- Monitoring travel time.

2.3.1 Tracer Selection

Because of the relatively close distance to TW-1 (50 feet), the findings from MW-SAT will help focus the frequency, analytes, and sampling procedures at the more distal, conventional monitoring wells (MW-UPA, MW-MPA, and MW-LPA). Establishing the hydrodynamics of solute transport in each sand interval will support evaluating redox, cation exchange, major constituent attenuation, SAT and the leaching of metals.

Evaluating advection, dispersion, diffusion, and the mixing between recharge and native groundwater in each sand interval requires tracking the migration of a conservative constituent, or tracer, past the MW-SAT. Chloride has been selected as a tracer to monitor migration of recharge through the aquifer at the SWIFTRC.

A tracer should exhibit the following two important characteristics:

- Non-reactive behavior between water types and minerals in the aquifer
- Significantly differing concentrations in the recharge and native groundwater.

Because it displays elevated concentrations in groundwater from the PAS, behaves conservatively in the aquifer environment, and exhibits low concentrations in treated water, fluoride has been used as a tracer during groundwater studies performed in the Virginia Coastal Plain. Yet, fluoride concentrations in groundwater from the UPA, MPA, LPA (0.41 to 0.52 mg/L) differed little from the SWIFTRC SWIFT Water projections (0.57 mg/L), so fluoride will not be used.

By comparison, chloride, a relatively inert ion, displayed significantly differing concentrations between recharge (220 mg/L) and groundwater produced from the three aquifers (1,970 to 2,760 mg/L). During column testing, personnel from HRSD developed a strong, reproducible correlation between chloride concentrations and specific conductivity measurements. Accordingly, HRSD operators will use specific conductivity as the primary indicator for tracking the arrival of recharge water at MW-SAT and the other monitoring wells. HRSD will confirm measurements by collecting samples for laboratory analysis of chloride.

Moreover, other researchers have pointed to the correlation between specific conductivity and chloride concentrations in a water sample (Hem, 1985). Often chloride concentrations make up 20 percent of a specific conductivity measurement. Consistent with this relationship, the SWIFT Water and groundwater are expected to exhibit markedly differing specific conductivity measurements. Yet, a specific conductivity measurement involves ions other than chloride that will react in the aquifer environment. Thus, a specific conductivity measurement does not qualify as an acceptably inert tracer but can be used as a screening indicator of chloride concentrations.

2.3.2 Estimated Travel Time

Located only 50 feet away, recharge may reach at least some of the screen intervals in MW-SAT relatively rapidly. If recharge spreads evenly across the eleven screen intervals, totaling 380 feet in length, HRSD will need to recharge 5.8 million gallons (MG) before it arrives at MW-SAT (Table 2-3). Dividing the volume by the recharge rate (1 million gallons per day; 1 mgd) provides the time (5.8 days) for recharge to arrive at MW-SAT.

Table 2-2. Volumes and times for recharge to reach intervals in MW-SAT, MW-UPA, MW-MPA, and MW-LPA

Monitoring Well	Recharge Entering Well Screens	Without Dispersion Volume (MG), Time (days)	With Dispersion in Sand Aquifer Volume (MG), Time (days)
MW-SAT ¹	All screens ³	5.8	2.1
	Top UPA Only ⁴	0.4	0.14
	UPA Only ⁵	2.1	0.8
	UPA and MPA ⁶	3.9	1.5
MW-UPA, MW-MPA, & MW-LPA	All screens ³	363	254
	Top UPA Only ⁴	24	17
	UPA Only ⁵	133	94
	UPA and MPA ⁶	251	176

Notes:

- ¹ MW-SAT located 50 feet away from TW-1
- ² MW-UPA, MW-MPA, MW-LPA located at a minimum distance of 280 feet from TW-1
- ³ All screen intervals in TW-1 total 385 feet
- ⁴ Top screen in UPA equals 25 feet in length
- ⁵ Screen length in UPA equals 140 feet
- ⁶ Screen length in UPA and MPA equals 265 feet

Because recharge is assumed to spread evenly across the eleven screens, this duration represents the maximum time for recharge to reach MW-SAT. However, several factors can reduce the time for recharge to arrive at a monitoring point, including hydrodynamic dispersion (longitudinal dispersion and diffusion) in the aquifer, recharge channeling along higher permeability pathways, and density segregation. Considering dispersion, it is expected that recharge water will reach MW-SAT after approximately 2 MG, taking an estimated 2 days.

Without knowing when recharge enters a screen interval, determining accurate travel times and other hydrodynamic coefficients could prove difficult, particularly if recharge does not enter an individual screen interval upon start-up. However, the present scheme will support estimating hydraulic coefficients in screens that will obviously receive recharge at start-up, thus, yielding the most conservative travel times, an important concern to groups regulating MAR facilities and HRSD. In deeper screens that experience a delayed start, HRSD will rely on comparing the breakthrough of a tracer with the breakthrough of other constituents for estimating a semi-quantitative solution for constituent attenuation.

Operational MAR wells impose a hostile environment on sensitive, downhole instruments like in-hole flowmeters, particularly those positioned in the screens. Frequent, bi-directional turbulent flow during backflushing events will entrain dense clouds of abrasive particulates and turbidity that will damage instruments stationed in screen intervals, reducing their accuracy or causing failure. Maintaining a network of downhole instruments protected from turbulent flow, particulates and turbidity probably requires installing a well adjacent (< 10 feet) to TW-1 with identical screen intervals.

The velocity of the recharge traveling through the aquifer decreases with distance from the recharge well. In other words, recharge water close to the recharge well travels in the aquifer at higher velocities than recharge water further away from the well. The travel times observed at MW-SAT will be used, in conjunction with observed travel times to the three conventional MWs, to develop a time vs distance relationship curve for the recharge bubble for the upper, middle and lower Potomac Aquifer zones at

the SWIFTRC. This will be used to refine earlier estimates of travel time derived by numerical and spreadsheet modeling for the full-scale operation scenario.

2.3.3 Breakthrough Curve

Characterizing the relationship between advection, dispersion, and diffusion in each sand interval screened by MW-SAT using chloride as a tracer will establish a sound basis for evaluating groundwater and solute velocities. The curves will support evaluating the fate of constituents in the PAS other than chloride, including the attenuation of major ions, trace metals, nutrients, and trace organic components undergoing SAT (Figure 2-5). The concentration versus time relation at the monitoring point is often called the breakthrough curve. The geometry of the curve for an individual solute in relation to the tracer's curve can help an analyst interpret the type of attenuation experienced by the solute. The field scale analysis will be compared against the soil column testing results that HRSD is conducting.

To develop the breakthrough curves, HRSD operators will sample from the eleven sampling ports in MW-SAT to intercept tracer and other important constituents as they pass the well. Concentrations of chloride, a selected tracer will decline to a stable threshold as recharge passes the well. Thus, HRSD will employ mass balance techniques to develop a breakthrough curve based on percentage of recharge water in the sample plotted against time. HRSD will employ the same approach for evaluating other constituents depending on whether concentrations are greater in the recharge or native groundwater.

In deeper screens, recharge water may not enter the screens for a significant period after starting operations. In addressing the deeper intervals, HRSD will compare the breakthrough of a tracer with the breakthrough of other constituents for estimating a semi-quantitative solution for constituent attenuation. Depending on the empirical results, HRSD may examine several other important factors such as the adsorption capacity of aquifer materials.

An important factor in reducing transport data and interpreting breakthrough curves will involve knowing the exact linear distance between TW-1 and MW-SAT. Because of the depth of the wells, the distance may differ between shallow and deeper screen intervals, depending on the slope of each wellbore away from true plumb. The exact distances between the screen intervals in TW-1 and MW-SAT will be obtained using gyroscopic surveys conducted in the two wells used to estimate distances based on the slope in each.

2.3.4 Hydraulic Monitoring

MW-SAT will contain pressure transducers set at the base of the UPA, MPA, and LPA. The transducers will record water levels to HRSD's distributed control system. The measurement frequency will be modified to obtain more detailed, or less noisy data as the situation dictates. Water level measurements in TW-1 showed heads varying by less than one foot between the three aquifers. As the depth of setting accuracy for a transducer elevation may exceed 1.0 foot in a FLUTE sampling system, employing transducers in each of the 11 screen interval to evaluate heads in detail holds little relevance, and may introduce significant uncertainty in evaluating the relationship in heads between individual screen intervals. Therefore, monitoring the water level in one selected screen from each of the three aquifer zones is sufficient.

2.3.5 Water Quality Monitoring

The FLUTE sampling system installed in MW-SAT will consist of polyvinylidene fluoride (PVDF) tubing running from a sample port situated in each well screen to the ground surface. PVDF tubing exhibits the same inert, chemical characteristics as Teflon, but is stronger and less likely to kink during installation or sampling operations. Collection of rinseate samples by FLUTE with analysis for CECs has yielded less than method detection limits for all constituents.

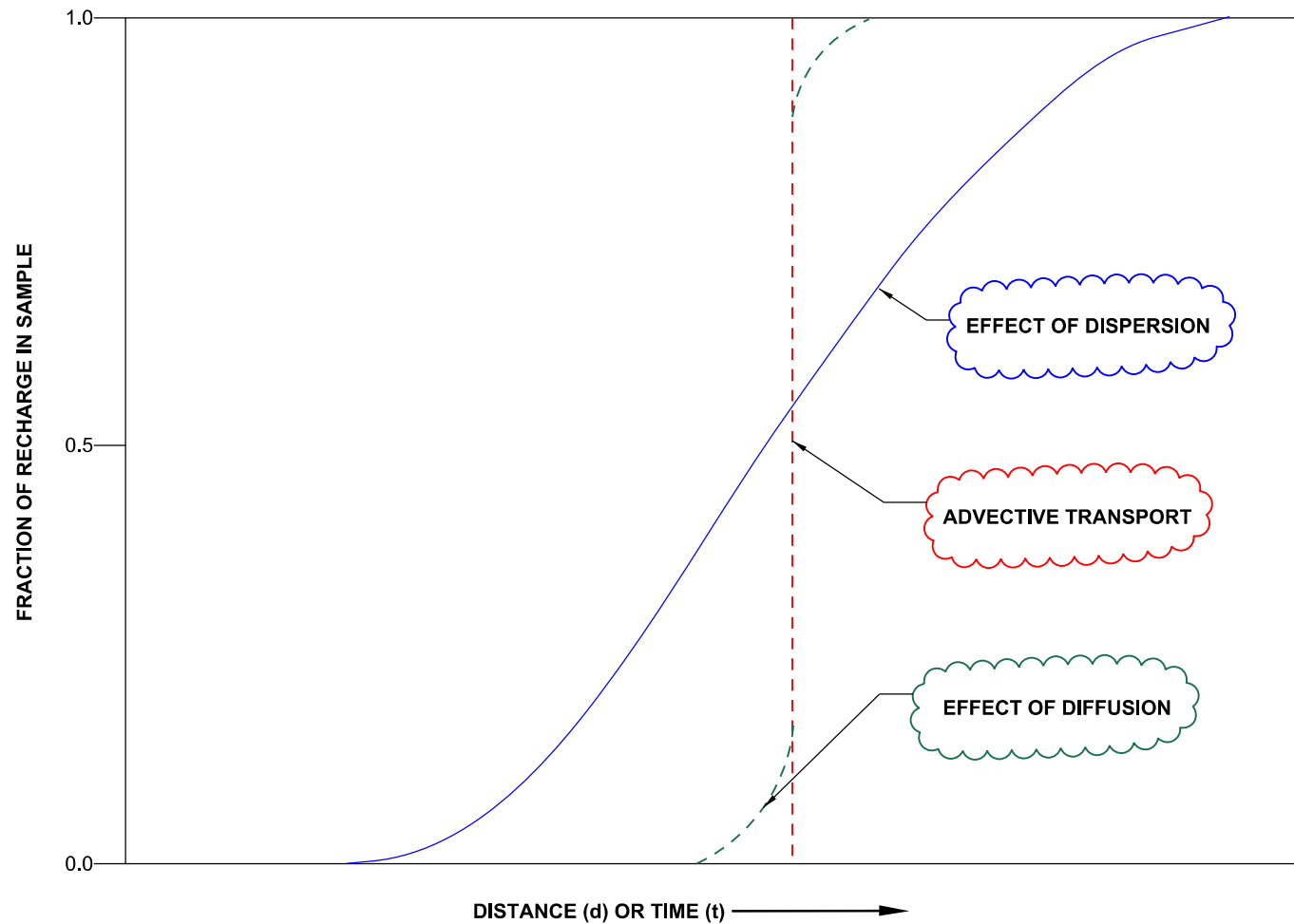
Sampling personnel will employ a nitrogen source to purge the tubing and then withdraw samples from each interval. The pumping system accommodates filling sample bottles quickly and efficiently. The system should also allow attachment of tubing for connection to a flow-through cell to measure important field chemistry constituents (temperature, pH, specific conductivity, ORP, and DO). Tentatively, the 11 sampling tubes will be run into the piloting area of SWIFTRC.

A series of background groundwater samples (at least 4) will be collected from each of the eleven ports installed in the center the screen intervals, prior to starting MAR operations. Monitoring the recharge as it first flows past MW-SAT in each affected screen interval represents a critical element in discriminating between advective and dispersive transport of a solute in the PAS. Accordingly, samples collected must capture the change in water chemistry as recharge displaces groundwater in the sand beds of the PAS. This monitoring will require recording specific conductivity measurements, and analyzing chloride in the field using titrators every 12 hours after MAR operations commence at 1 mgd. Baseline samples should be collected for all parameters in Table 2-4. Whole water samples will also be archived (collected in 4L amber glass and stored at -18C) for future use in retrospective analyses. Further, while Tables 2-4 and 2-5 document the collection of routine sample parameters, additional analytes may be included as part of on-going research studies (e.g., antibiotic resistance genes, microbial community analyses).

Once recharge is detected in a specific interval using specific conductivity and chloride, operators should plan on collecting samples for a more comprehensive suite of analytes at 12 hour intervals in the upper most screen intervals of MW-SAT. Specific conductivity and chloride measurements collected at 24-hour intervals should continue in deeper screens until measurable changes in water chemistry are encountered. At a minimum, all regulatory limit parameters and performance indicators should be measured on a consistent basis. These parameters are identified in Attachment B of the UIC Inventory.

Once specific conductivity, chloride, calcium, sodium, magnesium, potassium (cations), sulfate, alkalinity (anions), iron, manganese, aluminum (trace metals), nitrate, TKN, nitrite, total phosphorous, ortho-phosphate as P (nutrients), TOC/DOC and total dissolved solids (TDS) in samples from a sand interval in MW-SAT equal the concentrations observed in samples from the SWIFT Water, or are stable after three samples, operators can reduce the sampling frequency for these constituents, and the interval, to weekly for one month and then monthly, thereafter, with the exception of arsenic. Samples should continue to be collected and analyzed for arsenic on a weekly frequency over the duration of the project.

Daily monitoring for specific conductivity and chloride in deeper screen intervals should continue until concentrations change, indicating the presence of recharge. Once recharge is detected, operators should collect samples for a comprehensive list of parameters daily. Once concentrations of the constituents from the MW equal the concentrations in the SWIFT Water or are stable after three samples, sampling frequency can be reduced to monthly.



Legend

C - Sample Concentration

C_0 - Concentration in Plant Effluent

Note:

Chloride concentrations in recharge will run significantly lower than native groundwater, so breakthrough curve will reflect a negative concentration gradient.

Figure 2-5
**Conceptual Relationships
 Between Advective, Diffusive and
 Dispersive Solute Transport**
 Hampton Roads Sanitation District
 Virginia Beach, VA

ch2m

Table 2-3. Summary of Analytes and Collection Frequency For MW-SAT

Analyte	Units	Sample Type	Sample Frequency (once tracer is identified)	Sample Frequency after MW-SAT concentration = SWIFT Water concentration-(long term)
pH, ORP ³ , Dissolved oxygen, temperature, and turbidity	standard units, mV C, and NTU, respectively	Measure field chemistry	Every 12 hours	Daily for one week then monthly thereafter
SWIFT Water Regulatory Limits ¹ (PMCLs, TOC, etc. – see Table 2-1)	Various	Grab/Lab	Daily	Daily for one week then monthly thereafter
SWIFT Water Performance Indicators (see Table 2-1))	Nanograms per liter (ng/L)	Grab/Lab	Daily	Daily for one week then monthly thereafter
Specific Conductivity	ms/cm	Measure field chemistry	Every 12 hours after starting MAR operations at 700 gpm	Daily for one week then monthly thereafter
Field Chloride	mg/L	Measure field chemistry	Every 12 hours after starting MAR operations at 700 gpm	Daily for one week then monthly thereafter
Field Sulfide as S, Field Sulfate as SO ₄ , Field Iron (ferrous as Fe ²⁺), Field Iron (total)	mg/L	Measure field chemistry	Daily	Daily for one week then monthly thereafter
Alkalinity as CaCO ₃	mg/L	Grab/Lab	Daily	Daily for one week then monthly thereafter
Arsenic dissolved & total	mg/L	Grab/Lab	Weekly for duration of project	Weekly for duration of project
Aluminum, Iron & Manganese - dissolved and total,	mg/L	Grab/Lab	Every 12 hours	Daily for one week then monthly thereafter
Magnesium, potassium, sodium, & calcium total	mg/L	Grab/Lab	Every 12 hours	Daily for one week then monthly thereafter
TDS, Sulfate, chloride, alkalinity, fluoride, Silica as SiO ₂	mg/L	Grab/Lab	Every 12 hours	Daily for one week then monthly thereafter
Nitrate/Nitrite-N, Nitrate as N, Ammonia & Total Kjeldahl Nitrogen	mg/L	Grab/Lab	Every 12 hours	Daily for one week then monthly thereafter
Dissolved organic carbon	mg/L	Grab/Lab	Daily	Daily for one week then monthly thereafter
Total phosphorus & Orthophosphate as P	mg/L	Grab/Lab	Every 12 hours	Daily for one week then monthly thereafter
BOD5 & COD	mg/L	Grab/Lab	Every 12 hours	Daily for one week then monthly thereafter

Note:

¹ Specific analytes with a more frequent sampling schedule are noted elsewhere in this table.

2.4 Conventional Monitoring Wells MW-UPA, MW-MPA, and MW-LPA

Results of the early monitoring in MW-SAT should prove invaluable for guiding the frequency of sampling at the conventional monitoring wells MW-UPA, MW-MPA, and MW-LPA. Similar to the analysis performed for MW-SAT (Table 2-4), if water spreads evenly across all eleven screen intervals, recharge should not reach the conventional monitoring wells until HRSD injects 363 MG (363 days) without dispersion, or 254 MG (254 days), considering dispersion. If recharge only exits screens in the UPA, water will reach MW-UPA in 133 and 94 days, for no dispersion and dispersion scenarios, respectively.

Several factors can reduce the time for recharge to arrive at a monitoring point, including longitudinal dispersion in the aquifer, recharge channeling along higher permeability pathways, and density segregation. The following equation estimates the effects of hydrodynamic dispersion:

$R' = R + 2.3VD \times R$, Where

R = radial distance from injection to monitoring point (feet)

R' = radial distance of travel with dispersion (feet)

D = dispersion coefficient; 3 feet for sand aquifers (Bear, 1972).

2.4.1 Hydraulic Monitoring

Each conventional monitoring well will be equipped with a pressure transducer that will record water levels at 10-minute intervals to the SCADA system. These data will help characterize the hydraulic response in each aquifer to recharge at TW-1. Also, similar to head data collected at MW-SAT, these data will help detect clogging during MAR operations by comparing the draw-up in the aquifer at MW-UPA, MW-MPA, and MW-LPA to the draw-up in TW-1. Any analysis of drawdown from MAR operations in MW-UPA, MPA, or LPA needs to consider and remove the drawdown caused by sampling pumps installed in each well

2.4.2 Water Quality Monitoring

Similar to the MW-SAT, 4 background groundwater samples will be collected from MW-UPA, MW-MPA, and MW-LPA, prior to starting MAR operations, and analyzed for the comprehensive list of parameters appearing in Table 2-2. After commencing MAR operations, specific conductivity and chloride (field titrators) will be measured daily at the conventional monitoring wells. Upon detecting a change in these measurements suggesting the arrival of recharge, the daily samples will be analyzed for a significantly greater number of constituents (Table 2-5).

Once specific conductivity, chloride, and the cations, anions, trace metals, nutrients, TOC/DOC, and TDS equal the measurements in the SWIFT Water, or are stable after 3 samples, operators can reduce the sampling frequency for these constituents to monthly thereafter with the exception of arsenic. Samples should continue to be collected and analyzed for arsenic on a weekly frequency.

Sampling for SWIFT Water performance indicators (SWPI) in MW-UPA, MW-MPA, and MW-LPA will not commence until the following two criteria are met in order:

1. SWPI have already been detected in MW-SAT
2. The presence of recharge is detected in MW-UPA, -MPA, and -LPA

Upon meeting these criteria, the conventional monitoring wells will be sampled for SWPI weekly.

If there is a marked increase in SWPI concentrations, sampling frequency should increase to daily, until concentrations equal those recorded in the SWIFT Water. After concentrations match SWIFT Water, the operators can reduce the frequency to once monthly.

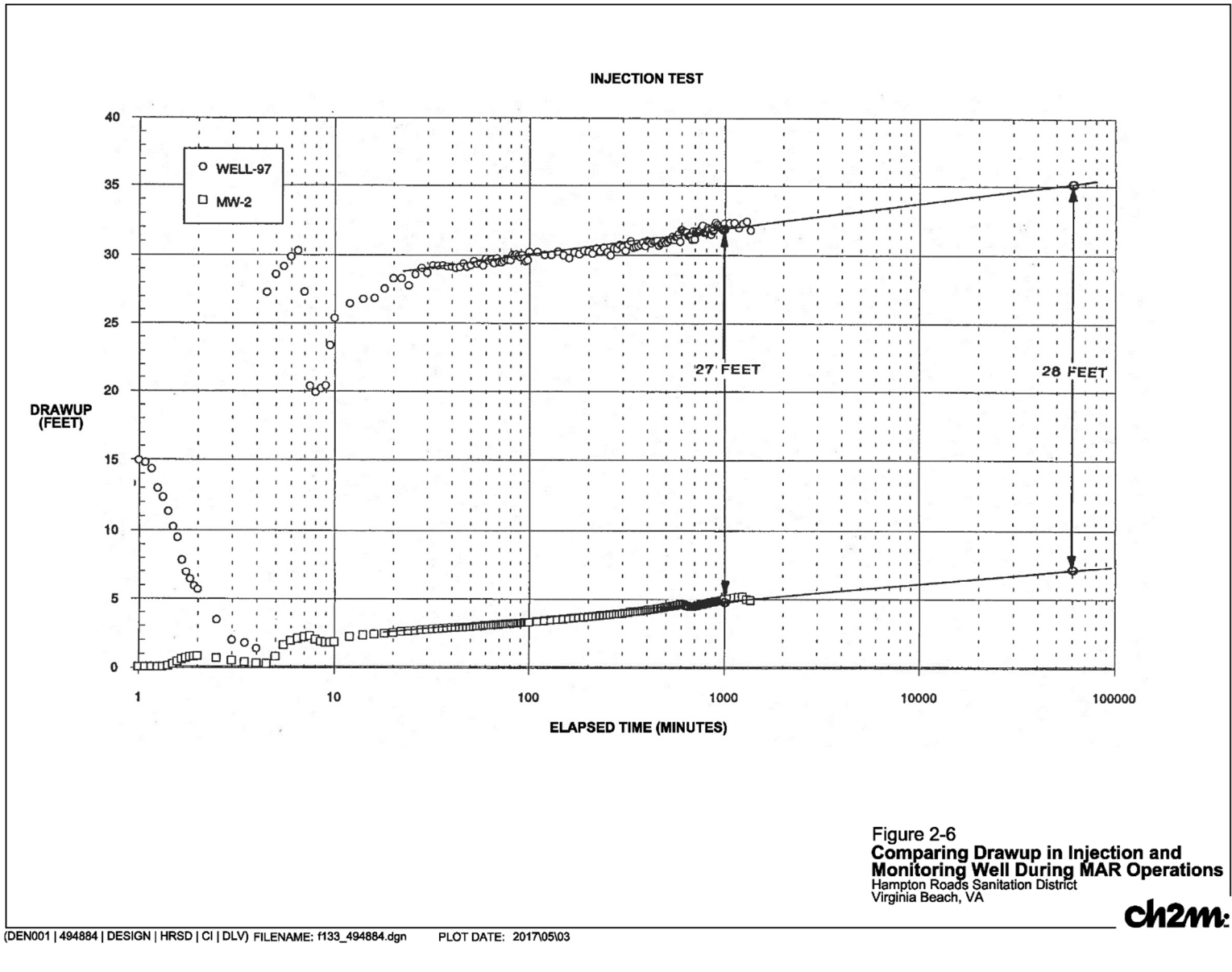


Table 2-4. Summary of Analytes and Collection Frequency For MW-UPA, MW-MPA, and MW-LPA

Analyte	Units	Sample Type	Sample Frequency (once tracer is identified)	Sample Frequency after MW-SAT concentration = SWIFT Water concentration-(long term)
SWIFT Water Regulatory Limits ¹ (PMCLs, TOC, etc – see Table 2-1)	Various	Grab/Lab	Weekly	Monthly
SWIFT Water Performance Indicators (see Table 2-1)	ng/L	Grab/Lab	Weekly	Quarterly
pH, ORP, DO, Temperature and Turbidity	standard units, mV, mg/L, °C, & NTU, respectively	Measure field chemistry	Daily	Monthly
Specific Conductivity and Field Chloride	ms/cm; mg/L	Measure field chemistry	Daily after starting MAR operations at 700 gpm	Monthly
Field Sulfide as S, Field Sulfate as SO ₄ , Field Iron (ferrous as Fe ²⁺), Field Iron (total), & Field Alkalinity as CaCO ₃	mg/L	Measure field chemistry	Weekly	Weekly
Aluminum, Iron, & Manganese, dissolved and total	mg/L	Grab/Lab	Daily	Monthly
Arsenic dissolved & total	mg/L	Grab/Lab	Weekly	Weekly
Magnesium, Potassium, Sodium, & Calcium total	mg/L	Grab/Lab	Daily	Monthly
TDS, Sulfate, Chloride, Alkalinity, & Fluoride	mg/L	Grab/Lab	Daily	Monthly
Nitrate/Nitrite-N, Nitrate as N, Total Kjeldahl Nitrogen & Ammonia as N	mg/L	Grab/Lab	Daily	Monthly
Dissolved organic carbon	mg/L	Grab/Lab	Weekly	Monthly
Total phosphorus & Ortho-phosphate as P	mg/L	Grab/Lab	Weekly	Monthly
BOD5 & COD	mg/L	Grab/Lab	Weekly	Monthly

Note:

¹ Specific analytes with a more frequent sampling schedule are noted elsewhere in this table.

Contingency Plan

The contingency plan describes measures for responding to non-routine situations arising during MAR operations. Obvious situations might involve recharging compromised water quality into the PAS or encountering a constituent that exceeds Safe Drinking Water Act (SDWA) Primary Maximum Contaminant Levels (PMCL) in one of the monitoring wells. Other situations might entail less compelling, yet equally important circumstances affecting MAR operations, such as combating declining injectivity in TW-1 or rising concentrations of TSS in the recharge.

As MAR operations progress, HRSD personnel may amend this plan to add situations not covered in this version of the Contingency Plan

3.1 Hydraulic

Hydraulic situations that could compromise the performance of MAR project include declining injectivity at TW-1, elevated TSS in the recharge as determined from BFI and MFI testing results, and excessive mounding in the PAS, reducing the head available for recharge.

3.1.1 Loss of Injectivity at TW-1

HRSD will track and evaluate injectivity at TW-1 on a weekly basis. A loss in injectivity corresponds to a decline of 15 percent or greater, as measured from the original tested value upon commencing MAR operations. This magnitude of loss will reduce the injection capacity of TW-1, compromising operations at the SWIFTRC.

Upon identifying a measurable loss in injectivity, the backflushing frequency should be increased to once per day until the decline is halted or reversed. Moreover, the latest BFI and MFI testing results should be examined to determine if TSS loading has recently increased. If the injectivity loss is not arrested by increasing the backflushing frequency, the following measures should be considered:

- Dropping the recharge rate at TW-1
- Initiating non-intrusive rehabilitation techniques
- Initiating intrusive rehabilitation techniques

The severity of corrective actions that should be taken in addressing declining injectivity in TW-1 depends on the time remaining for operation of the SWIFTRC. If the project is close to ending, MAR operations should continue without taking unnecessary steps to correct the issue. If a longer period of service for TW-1 is required, HRSD may consider treating TW-1 using non-intrusive measures like introducing chemicals for shock chlorination, biodispersants, or acid in the annular space of TW-1. These techniques can partially restore the injectivity of a MAR well.

If the injectivity is not restored by increasing the backflushing frequency or using non-intrusive rehabilitation techniques and the SWIFTRC will continue operating for more than 12-months, TW-1 will need to be rehabilitated using invasive techniques. In a well containing 380 feet of screen like TW-1, invasive rehabilitation can take 2 to 3 months to complete. Invasive well rehabilitation should consist of the following steps:

- Performing a pre-rehabilitation injectivity test
- Removing the backflushing pump
- Conducting a pre-rehabilitation video survey
- Swabbing the screen intervals with the appropriate chemical treatments
- Installing a test pump and implementing over-pumping development

- Removing the test pump
- Conducting a post-rehabilitation video survey
- Re-installing the backflushing pump, column and downhole valve
- Conducting a post rehabilitation injectivity test using the permanent equipment

If the pre-rehabilitation video survey indicates that the well screen is clear of sedimentation, biofouling, or metal precipitates, an explanation for the loss in injectivity may originate from the dispersion or swelling of interstitial clays in the PAS (formation damage). MAR operations may have initiated formation damage through cation exchange between clays and the recharge, or the reversal of the conditioning process by the continual injection of low ionic strength, recharge. This situation requires applying a second clay conditioning episode using the same or a differing conditioning agent.

3.1.2 Elevated TSS Loading to SWIFT Water

If BFI or MFI testing reveal an increase in TSS loading in the SWIFT Water over three consecutive testing episodes, HRSD should consider taking the following steps:

- Getting filtrate samples analyzed by x-ray diffraction and energy dispersive x-ray analysis.
- Increasing the backflushing frequency
- Installing a bag or cartridge filter system on piping leading to the wellhead
- GAC backwashing to better remove GAC fines

Analyzing filtrate samples using x-ray diffraction or energy dispersive x-ray analysis will determine the mineralogical and chemical composition of the TSS. If the analysis reveals that TSS originates from treatment chemical residuals or precipitates, the treatment process should be examined for the possibility of eliminating these potential clogging agents. In the interim, the backflushing frequency should be increased at TW-1 to preclude the accumulation of TSS in the well screen and filter pack. If adjusting a treatment process proves problematic, HRSD could retrofit the recharge wellhead piping with a bag or cartridge filter system to intercept TSS before it enters TW-1. These small filtering systems often require maintenance at a weekly to daily frequency depending on the TSS concentrations in the SWIFT Water.

3.1.3 Mounding in the PAS

Mounding will entail a rebound in ambient water levels in the PAS caused by MAR operations at TW-1. The rise in water levels will reduce the available head for recharge. Given the size of the PAS, MAR activities at TW-1 should not influence ambient static water levels to a significant degree. ASR operations in the UPA and MPA at the City of Chesapeake since 1991 have left a surplus exceeding 1 billion gallons of recharge without noticeably increasing local ambient water levels. Yet, aquifers can respond in an unexpected manner to MAR operations.

Detecting an increase in ambient water levels will require careful interpretation of water levels in TW-1, MW-SAT, and the conventional monitoring wells during recharge, during backflushing, and during periods when the SWIFTRC is idle.

To continue MAR operations while maintaining injection capacity, HRSD should consider increasing the backflushing frequency at TW-1. This measure will help conserve injection heads by reducing well losses from clogging in TW-1. If wellhead pressures approach 30 pounds per square inch after increasing backflushing frequencies, HRSD should consider reducing the recharge rate in small increments until heads stabilize. Mounding in PAS should not significantly affect this 1 mgd project, but will influence the success of expanded, permanent MAR operations at Nansemond.

3.2 Water Quality

The regulatory monitoring and the critical control point protocols are intended to prevent exceedances of any PMCLs within the PAS as a result of the injection of SWIFT Water. If PMCL violations are confirmed in the SWIFT Water prior to injection, SWIFT Water will be diverted to the wastewater treatment facility until compliance with the PMCL is demonstrated. Similarly, violations of certain critical control point action values will result in a diversion of water away from the advanced water treatment system or away from the injection well (see Table 8 in Attachment B or Table 2-10 in Attachment G).

This section describes the contingency plans for addressing PMCL exceedances observed within the PAS as a result of the injection of SWIFT Water. Monitoring of the recharge water from MW-SAT and the conventional monitoring wells (MW-UPA, -MPA, -LPA) as identified in Table 2-4 and Tables 2-5 will be used to assess compliance with the PMCLs. Contingencies are only developed for situations when PMCLs are exceeded after sampling data has documented that recharge has migrated past MW-SAT and/or the conventional monitoring wells.

3.2.1 PMCL Violation and Reporting

If monitoring at MW-SAT and/or the conventional monitoring wells identifies an exceedance of a PMCL that cannot be justified by the constituents present in a field or lab blank, HRSD will collect an additional sample to confirm the results within 7 days of receiving the laboratory data. If the results appear related to sampling error or other factors, HRSD will provide an explanation in a report submitted to EPA. If a contravention of the PMCL is confirmed, HRSD will contact the EPA Region III's UIC Case Manager within 24 hours to provide notification of the exceedance and will write by certified mail to EPA within 7 days of the exceedance describing in detail the potential cause of the exceedance and corrective measures implemented to mitigate the issue. In the case of an exceedance, HRSD will make all efforts to track the source of a potential contaminant.

HRSD may make adjustments in the treatment process that aim to reduce the reactivity (passivate) of minerals in the PAS in situ. HRSD will increase the sampling frequency at MW-SAT, MW-UPA, -MPA, or -LPA, as appropriate, to track concentrations of the potential contaminant. If sampling results indicate that measures taken to passivate have proven successful, HRSD will document the actions. Conversely, if passivation measures fail to reduce concentrations of the exceedance below the PMCL, HRSD will halt SWIFTRC operations until an alternative solution is developed. HRSD will notify EPA of these actions through the hotline and in writing by certified mail within 7 days.

HRSD will submit the sample results on the following two forms: Monitoring Report Transmittal Sheet (T-VW-014) and Discharge Monitoring Reports, and send the reports to the EPA address identified below with copies of the reports provided to the Virginia Department of Health, Office of Drinking Water.

EPA Region III
Drinking Water/Groundwater Protection Branch
Water Protection Division
Monitoring Reports Unit
1650 Arch Street
Philadelphia, PA 19103-2029

References

Bear, J., *Hydraulics of Groundwater*, McGraw-Hill Publishing Company, New York, New York, 1979.

Reed, M.G., *Stabilization of Formation Clays with Hydroxy-Aluminum Solutions*, *Journal of Petroleum Technology*, (July 1972), Houston, Texas, 1972.

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Appendix 1

Standard Operating Procedure for
Applying Aluminum Chloride Treatment
at Lower Potomac Aquifer Monitoring
Well – MW-LPA

Standard Operating Procedure for Applying Aluminum Chloride Treatment at Lower Potomac Aquifer Monitoring Well – MW-LPA

1.0 Introduction

- A. This standard operating procedure covers the work, materials, and equipment necessary for the applying an aluminum chloride treatment in MW-LPA followed by adding potable water to displace the treatment solution into Lower Potomac Aquifer (LPA), storing the treatment solution, pumping treatment solution from the well, step drawdown testing, and injection testing in MW-LPA after the treatment.

2.0 Aluminum chloride solution

- A. Chemical treatment should commence by mixing a solution of 0.1 molar (M) aluminum chloride ($\text{Al}(\text{Cl})_3$) in potable water. The solution results in a $\text{Al}_3(\text{OH})_6^{3+}$ polyelectrolyte, featuring a + 3 charge beneficial for adsorption or cation exchange with sodium montmorillonite clays in the LPA. The solution is mixed thoroughly to preclude the precipitation to $\text{Al}(\text{OH})_3$. The liquid AlCl_3 and NaOH solutions shall roughly equal a concentration of 28 and 50 percent by weight (solution strength), respectively with water comprising the remainder (Figure A-1).

The recommended chemical amounts are based on treating a volume of aquifer extending 20 feet from MW-LPA (Table 1).

- B. Allowable percentages of impurities in the AlCl_3 solution shall not exceed the weight percentages appearing Table 2.

Table 1. Summary of Chemical Requirements

Well	Treatment Zone Top (feet below grade)	Bottom (feet below grade)	Screen Length (feet)	Total Solution ⁽¹⁾ (gallons)	Aluminum Chloride ⁽²⁾ (gallons)
MW-LPA	1230	1400	130	307000	11410
TW-1/UPA	505	755	110	260000	9880
TW-1/MPA	820	1090	125	295300	11200
TW-1/LPA ⁴	1230	1400	135	318000	12080

Notes:

¹ Volume out to 20 feet from MW-LPA: 0.1 M AlCl_3 & 0.2 M NaOH

² 28% strength AlCl_3 solution

³ 50% strength NaOH solution

⁴ Volume differs from MW-LPA because of differing wellbore volumes

Note volumes may change after pilot testing MW-LPA.

Table 2. Allowable Weight Percentages of Other Components in Aluminum Chloride Solution

Constituent	Concentration	Comment
	(%)	
Al as Al_2O_3	10.6	Minimum
Sulfur as SO_3	0.03	Maximum
Iron as Fe	0.00003	Maximum
Copper as Cu	0.00003	Maximum
Basicity as Free Al_2O_3	0.05	

C. CH2M will reject the liquid AlCl_3 solution if it contains any alum ($\text{KAl}(\text{SO}_4)_2 \cdot 12 \text{H}_2\text{O}$). The manufacturer or distributor will ship the liquid AlCl_3 solution in moisture-proof drums. The Contractor can submit other formulations and amounts for review by CH2M. Provide the necessary equipment as specified by CH2M which should include but not limited to the following:

1. Flatbed truck for transportation of chemicals and use as a work platform while administering treatment(s).
2. One 500 to 5,000 gallon mixing tank.
3. Three (3) sets of quick-close valves and necessary fittings.
4. Necessary tubing to run from the AlCl_3 drums into the mixing tank.
5. Chemical feed pumps for injecting AlCl_3 H into the mixing tank.
6. Paddles or electric stirring unit mounted in the tank to help mix AlCl_3 in water and help dissolve any quick-forming precipitates.
7. Necessary hose, valves, and fittings for water supply.
8. Necessary chemical piping to reach screen zone in MW-LPA (1,230 to 1,400 feet below grade).

2.01 Pumping Equipment

- A. Furnish a pump, discharge equipment, and piping for removing spent treatment solution out of MW-LPA and into the nearest available discharge inlet approved by the Owner.

2.02 Executing Aluminum Chloride Treatments

- A. The following describes administering aluminum chloride treatments in MW-LPA.
1. The Contractor will supply sufficient pipe or tubing to inject mixture comprising 0.1 M AlCl_3 into the screen zone of MW-LPA.
 2. Following well development, but prior to the aluminum chloride treatment in MW-LPA, use test pump to run a step drawdown test. Pump well at four rates for 60 minutes each up to 200 gpm.
 3. Set up materials and equipment in work-convenient locations around MW-LPA.
 4. Attach valves, fittings, and mixing tank to the chemical drums and water supply.
 5. Run chemical tubing into the screen zone of MW-LPA.

6. Introduce the AlCl_3 into mixing tank containing potable water first and then add NaOH. Add sufficient volumes to form 0.1 M mixture of AlCl_3 Table 3 provides volumes for each solution to achieve the appropriate mixture in a 1,000-gallon tank of water.

Table 3. Chemical Requirements in 1,000-gallon container

$\text{AlCl}_3^{(1)}$ (gallons)
47

Notes:

- ¹ Volume of 28% strength solution
- ² Volume of 50% strength solution

- B. Mix AlCl_3 and potable water together and ensure resulting solution appears clear with a turbidity less than 10 NTU before introducing solution into MW-LPA.
- C. Upon achieving a clear solution, inject into screen zone of well at a flowrate of 30 gpm.
- D. Continue mixing batches of AlCl_3 until reaching desired volume to treat aquifer extending to 20 feet from MW-LPA.
- E. After reaching treatment volume with AlCl_3 , continue a water feed at 50 gpm for 12 hours.
- F. After 12 hours, shut off the water feed and allow the well to stand idle for 14 days.
- G. During the idle period, re-install test pump capable of 200 gpm in MW-LPA to a depth around 300 feet below grade.
- H. On Day 15, start the test pump in incremental steps lasting 1 hour each, while increasing the flowrate to its capacity after four steps. Monitor water levels at one minute intervals during the pumping period.
- I. The Engineer will monitor important field chemistry (temperature, pH, specific conductivity, oxidation-reduction potential, dissolved oxygen) constituents over the pumping period.
- J. Continue pumping until the treatment fluid is removed from the well.
- K. After pumping out the treatment solution, install a 2-inch diameter drop to 120 feet below grade and run a 72-hour constant rate injection test.
- L. Inject water at progressively increasing rates for up 1-hour intervals up to a constant rate of 100 gpm.
- M. Measure water levels at one minute intervals over the duration of the test.
- N. CH2M may modify the testing protocol, but not the duration of the injection test. Proper precautions, as listed by the manufacturer, should be made by the Contractor during the handling and application of the chemical.

3.0 Chemical Contact Period

- A. Allow the aluminum chloride treatment solution to remain in the well for a minimum of 14 days following the treatment application. The final determination of the time will be made by CH2M.

4.0 Spent aluminum chloride Removal

- A. Pump spent aluminum chloride solution from MW-LPA for disposal in accordance with federal, state, and local regulations. HRSD has indicated that the spent aluminum chloride solution will benefit their waste water treatment processes at the Nansemond WWTP, and subsequently, the Contractor will convey the spent solution to the head of the WWTP. CH2M will monitor the specific conductivity and pH of water entering and exiting the tank. The Contractor will obtain written clearance from the Owner before disposing any water at the head of the WWTP. Continue to pump the spent solution out of MW-LPA until pH and conductivity readings approach pretreatment levels as determined by CH2M.
- B. Dispose of empty AlCl_3 drums in accordance with federal, state, and local regulations, or by returning to manufacturer.

5.0 Aluminum Chloride Treatment at MW-LPA

An AlCl_3 treatment and injection testing was conducted in MW-LPA during October 2017 and validated the effectiveness of the treatment approach for TW-1, scheduled for early January. Despite treating only a volume equal to 20 feet around the pilot well, the treatment appeared successful in maintaining the injectivity over a 7-day test that involved a recharging a volume of potable water that exceeded the treatment zone by several times. Lessons learned on procedural set up/introducing the treatment into the well will be incorporated into treating TW-1 along with treating at more discrete packered intervals than originally planned. Long-term evaluation of the aquifer treatment process will be obtained from operation of the demonstration facility and recharge into TW-1 and will be used to guide/adjust treatment and possibly design of the full-scale recharge wells.

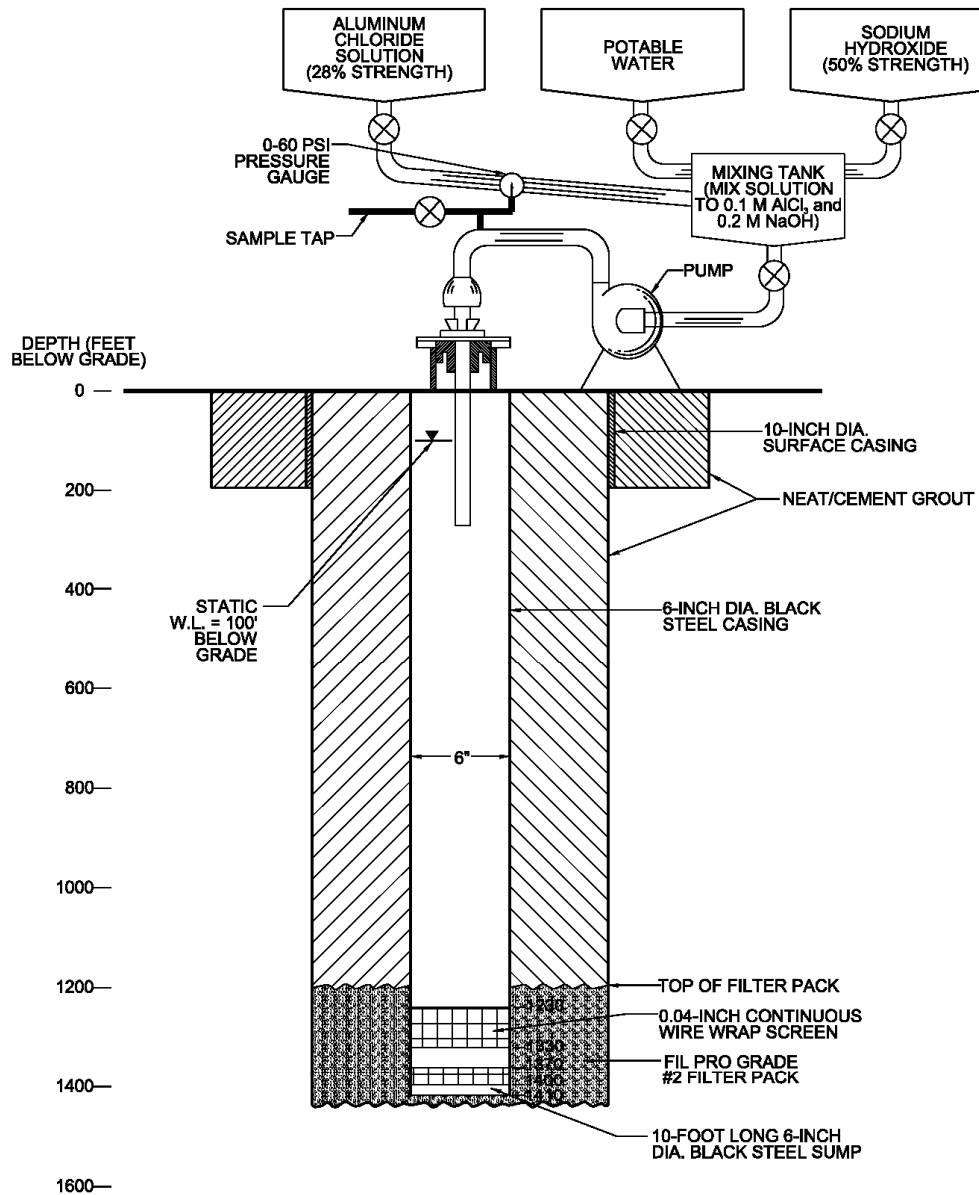


Figure A-1
Schematic of Hydroxy-Aluminum Chloride Treatment System
Hampton Roads Sanitation District
Virginia Beach, VA

ch2m:

(DEN001 | 494884 | DESIGN | HRSD | CI | DLV) FILENAME: f138_494884.dgn PLOT DATE: 2017/05/03